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A GIS-aided resource estimation of coalfields in Kangal basin, Sivas province, Turkey

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Abstract

This paper presents the procedures used for determining and defining the tonnage and grade of the coalfields of Kangal basin from the developed GIS-aided block model. In this work, firstly, all the lithological logs of drill holes and chemical analysis data of core in the basin were analyzed with the help of geostatistics, and then the digital raster maps of each one of the attributes such as the thickness, calorific value (LCV), ash content (AC%), moisture content (MC%), and surface maps of lignite seams were mapped in GIS environment. In the second stage, quantities of the overburden and resources with different categories were calculated on the basis of field-based quality and volume queries with the help of the digital maps on GIS platform. As a result, it was estimated that the Kalburçayırı field had a tonnage of 116 Mt of lignite with an LCV of 1308 kcal/kg, the Hamal field had a tonnage of 30 Mt of lignite with an LCV of 987 kcal/kg, and the Etyemez field had a tonnage of 48 Mt of lignite with an LCV of 1282 kcal/kg. Also it was estimated that almost 24,278,151 tons of lignite in the Hamal and Etyemez fields had a quality of less than 950 kcal/kg that could be directly fired without the blending process in the power plant. As a consequence, the Hamal and Etyemez fields should go into production as soon as possible and be fired in the power plant after being mixed with the lignite in the Kalburcayırı field so that they can be redounded to economy.

Keywords: *Kangal Lignite Basin, GIS, Geostatistics, Resource Estimation.*

1. Introduction

The Kangal lignite basin, which is one of the most productive lignite basins in Central Anatolia of Turkey, includes three lignite fields: Hamal, Kalburçayırı, and Etyemez [1]. In the basin, there is an active power plant with a capacity of 457 MW. More than 5.5 million tons of lignite burned per year by the power plant are currently being exploited in an open-cast mine in the Kalburçayırı field [2]. While the field's lignite reserve is gradually decreasing, the Hamal and Etyemez fields have not been excavated yet. In this framework, it is necessary to take these fields into operation and put forward the lignite potentials. Many resource estimations were made by MTA (Mineral Research & Exploration of Turkey) in the basin, however, the studies were carried out from1976 to1983 using polygonal methods without computer-aided design [3]. Afterwards, only Tercan [4] evaluated the Kalburcayırı coalfield using geostatistical estimations methods. The methods that were given in detail in Clark and Harper [5], Wackernagel [6], and Srivastava [7] produced more reliable results than the polygon methods because they allowed for distance and direction between samples in the estimation. In addition to geostatistical estimation, GIS appears today to be indispensable in mapping of estimation results, performing queries, and analysis of these results. In GIS, each layer of spatial data is linked to the corresponding tabular information [8, 9], and so the graphical and non-graphical data can be analyzed topologically [10]. The system replaced the old map-analysis processes, traditional drawing tools, and drafting and database technologies. For this reason, many mining companies have started to use the

technology as the preferred tool for mine planning, analysis, and management [11].
In this context, the objectives of this work were two-fold: a) to evaluate the resource of lignite in the Kangal basin with a more effective method, b) to apply the GIS techniques to a resource estimation for determining and defining the lignite tonnage and grade. The complete details of this work are described in the following sections.

2. Description of studied area and geological setting

Kangal lignite basin, which is located within the borders of Sivas province, consists of 3 separate lignite fields covering an area of 12.5 km^2 in total. These fields are the Hamal (2 km^2), Etyemez (2.5 km^2), and Kalburçayırı (8 km^2) fields (Figure 1).

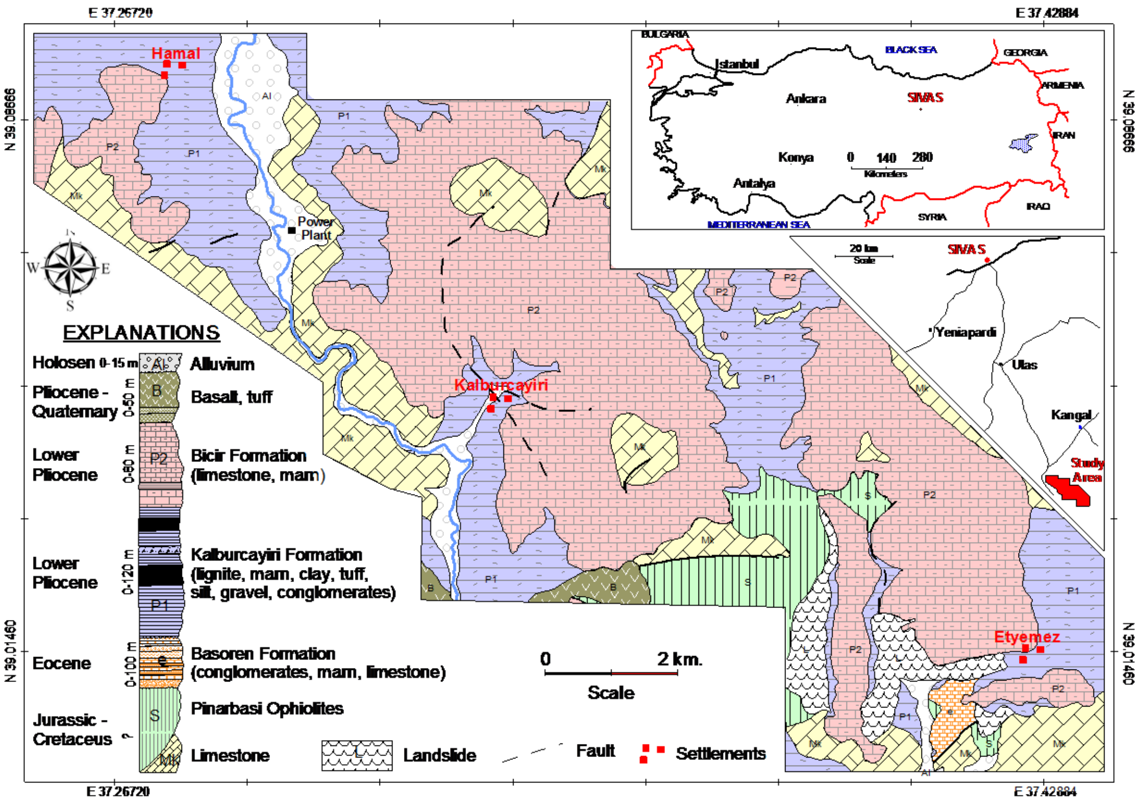

Figure 1. Geological and location map of studied area (modified from Utku [3], Narin, and Kavusan [12]).

The basin began to develop in the Late Paleocene and completed its evolution in the Middle Miocene. The basin comprises Middle Miocene–Late Pliocene fluvial, lake, and/or playa deposits [2, 12]. The lignites are developed in a limnic depositional environment according to the sediments found within [3, 12]. A generalized stratigraphical cross-section and geological map of the basin is given in Figure 1. According to geological investigations of the basin, Mesozoic (Jura-cretaceous) aged limestone and serpentinized ophiolites are observed in the basin. Cenozoic sediments are deposited with discordance on top of these units [3]. The Cenozoic is represented by Detritic Basoren formation (Cenozoic-Eocene) and Upper Miocene-Pliocene-aged Kalburçayırı and Bicir formation, which are terrestrial sediments. The Kalburçayırı formation includes two main coal seams alternating by silt stone, clay stone, tuffs, and marns, and the Bicir formation consists of marn and clay stones. As younger formations, Pliocene-aged basalt currents, Quaternary-aged terrace pebbles, alluvions, and hillside conglomerate are observed [12].
The coal seams that are generally horizontally deposited get thinner towards the basin sides and disappear. The total thickness of the coal- bearing series is roughly 80 m in the Kalburçayırı field. The series, from its base upward, comprises a sequence of clay, coaly clay, coal, carbonaceous shale, marl, and tuff with traces of coal [2]. Between the coal seams, there are tuffaceous sedimentary rocks whose thickness is 10 m. The total thickness of the coal-bearing series is about 72 m in the Hamal field. The series is of clayey

tuffaceous rocks, followed upward in the middle and upper parts of the series by greenish- gray marl and claystone. An approximately 4-m thick coal horizon is present in this coal-bearing sequence [13]. In the Etyemez field, seam thicknesses are 25 cm for the upper seam and 40 cm for the lower seam [3, 13].

3. Materials and method

3.1. Materials

Within the scope of the study, in the geostatistical analysis, lithological logs of 168 different drill holes performed by MTA until today and chemical analysis data of 1197 piece of core derived from these drill holes were used. These analyses are of lower calorific value (LCV), ash content (AC%), and moisture content (MC%). Of the drill holes performed in the basin, 38 of them belong to the northern sector of Kalburçayırı, 68 of them belong to the southern sector of Kalburcayırı, 20 of them belong to the Etyemez field, 33 of them belong to the Hamal field, and 9 of them belong to around the basin. In the GIS analyses, a topographic map of the basin with a scale of 1/25.000 and a cartographic map of the basin with a scale of 1/5000 and updated land use maps were used as raster data. As computer software, Datamine Studio 3.0 was used in the geostatistical analyses and MapInfo 9.0 software was used in the GIS analyses.

3.2. Method

In this work, initially, all the geologic and sampling data such as the x, y, z coordinates and dip and azimuth angles of drill holes, lithological definitions of core samples taken from drill holes, lower calorific value (LCV), ash content (AC%), moisture content (MC%) on an as-received basis, and core recovery were entered and maintained in an electronic database. These results were then classified according to field and as lower–upper lignite seam, and thickness weighted averages of quality values were taken. Each field and seam was handled separately, and accordingly, the thickness of lignite seam, upper and lower branches of lignite seams, LCV distribution, and AC% and MC% values along the basin were determined by geostatistical methods, and the kriging results were combined and kept as table data so as to be used later in the GIS analyses. In the estimations, respectively, the geostatistical methods that were explained graphically in Figure 2 were used.

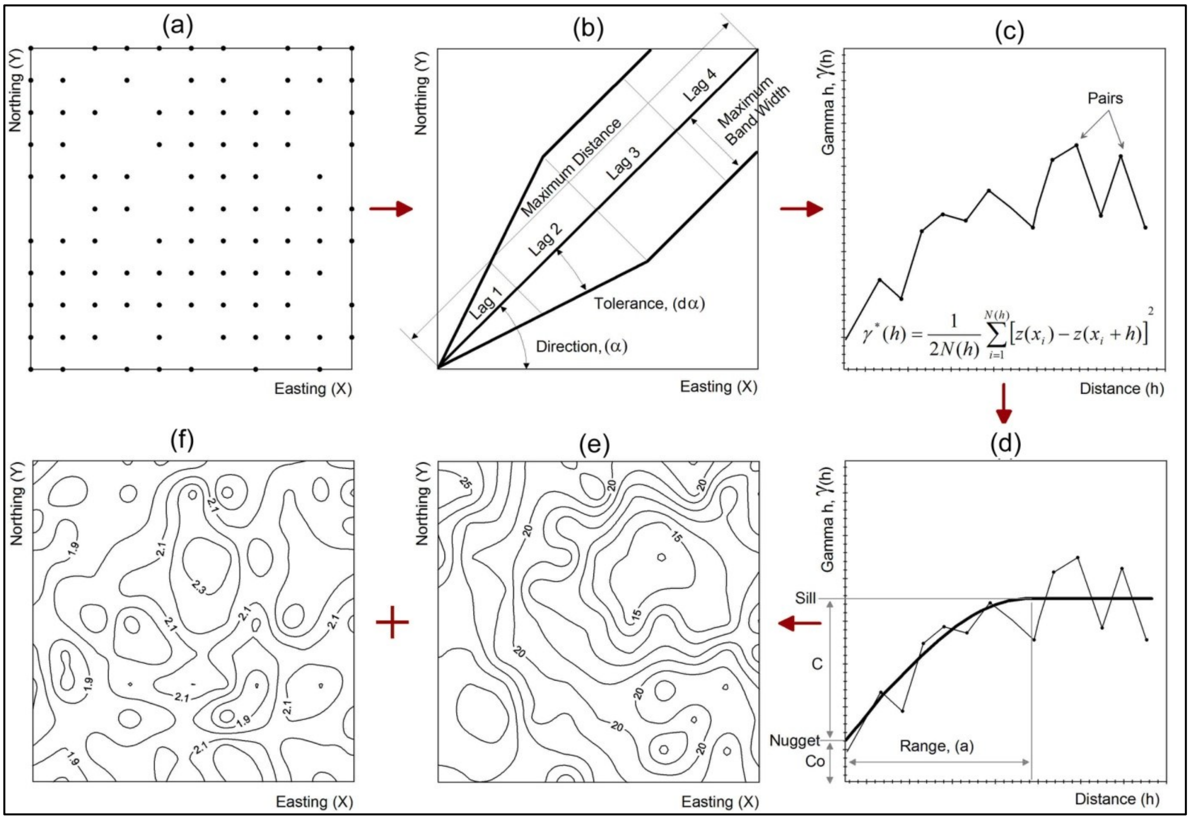

Figure 2. Graphical representations of geostatistical analysis stages: a) post plot of sample data, b) tolerance angles and distance tolerances, c) experimental semi-variogram, d) theoretical semi-variogram, e) contouring of kriged values, f) kriging error map [14].

In the next stage of the work, a topographic map with a scale of 1/25.000 and an updated land use map with a scale of 1/5000 were digitized using the GIS techniques, and accordingly, the digital elevation model of the basin and the graphical database were formed.
In the last stage of the work, the obtained table and graphical data were combined under the GIS environment and an opportunity was provided to realize the location-based analyses such as determination and mapping of quality and quantity distribution by GIS software. As a result, the relational database management system (RDBMS) was established to carry out the analysis based on the position between the graphical and the non-graphical data using the logical and topological relations (Figure 3).
Thanks to RDBMS, conditional analysis was performed on the graphical and table data selected from the computer screen. In this frame thickness, maps related to reserve and overburden layers, and out of these maps, volumetric outputs of coal and overburden were obtained using the cut/fill analysis.

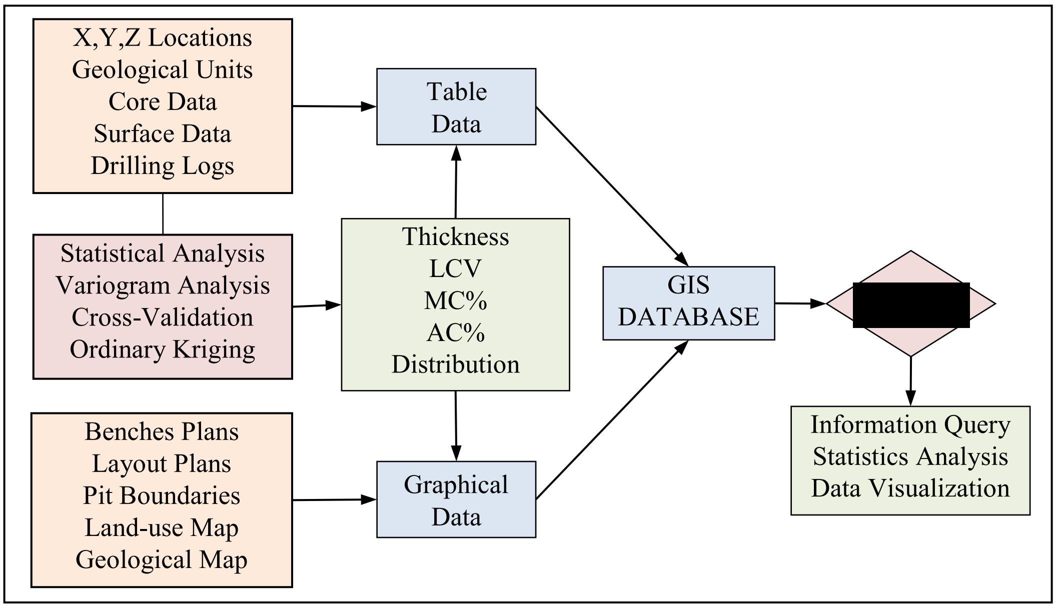

Figure 3. General flow chart of work.

4. Resource estimation

For the estimations, firstly, some descriptive statistics of the drill holes data were calculated (Table 1), and then the semi-variogram analyses of the variables such as the LCV, AC%, MC%, and thickness of lower and upper lignite seams were carried out for each field. The parameters obtained for 52 different theoretical semi-variogram models were verified by the cross-validation test technique and presented in Tables 2 (a and b). Then each field was divided into the blocks with optimum dimensions (20 x 20 m) with minimum kriging standard deviation, and the average quality values and the lignite thickness of each block were estimated by the determined theoretical semi-variogram models and the ordinary block kriging method. Finally, in this stage, the estimation results were saved to database as a spreadsheet format shown in Table 3 so as to be analyzed and mapped in the GIS-based software.
In the preparation of graphical data, first of all, the topographic and geologic maps with the scale of 1/25.000 and updated land use maps of Kalburçayırı field in April 2015 were transferred to the computer using a scanner. Then these maps were digitized in Universal Transverse Mercator (UTM) Zone 37 and European 1950 datum. As the second stage in the preparation of graphical data, the raster maps of each attributes such as LCV, AC%, MC%, and surface maps of the lower and upper lignite seams were prepared in the GIS environment (Figures 4-6). In these raster maps, 1 cm^2 cells were used in the grid structure in order to make a more detailed analysis. In this way, the GIS analysis was made possible by associating the generated graphical and table data.

Table 1. Descriptive statistics of upper and lower seams of fields.

Variable		Thickness of US	MC (%) of US	AC (%) of US	LCV (kcal/kg) Of US	Thickness of LS	MC (%) of LS	AC (%) of LS	LCV (kcal/kg) of LS
Kalburçayırı Northern Sector	Min.	0,15	26,00	14,99	35,00	0,10	37,86	14,82	622,61
	Max.	16,10	55,50	40,31	2197	12,45	54,62	36,95	1881,42
	Mean	5,91	46.27	19.78	1249.27	6,22	47.91	22.93	1340.77
Kalburçayırı Southern Sector	Min.	0,15	29,82	8,17	474	0,20	16,73	4,84	609,67
	Max.	15,70	60,94	39,01	2120,51	12,80	59,85	34,32	5170,27
	Mean	7,21	51.62	17.92	1307.8	5,73	48.14	21.25	1327,00
Hamal Field	Min.	0,10	38,63	13,91	215,00	0,40	41,12	15,77	665,26
	Max.	5,45	61,16	41,49	1992,50	18,25	55,48	29,31	2410,10
	Mean	1,89	47.86	22.11	901.78	11,70	46.77	21.90	999.10
Etyemez Field	Min.	1,75	45,16	14,24	499,38	0,50	29,01	13,75	1069,24
	Max.	16,90	59,35	25,02	2695,59	10,20	51,08	27,16	2315,78
	Mean	8,50	49.58	20.46	1224.87	4,61	45.60	21.78	1476.30

Note: *US: Upper Seam, LS: Lower Seam, UpSE: Upseam Surface, BsSE: Bottomseam Surface.

Table 2a. Semi-variogram parameters of upper and lower seams of fields.

Variable	Kalburçayırı Northern Sector				Kalburçayırı Southern Sector			
	Model	Nugget Effect (C_o)	Sill (C)	Range (A), m	Model	Nugget Effect (C_o)	Sill (C)	Range (A), m
Thickness of US	Spherical	1	18	964	Spherical	4	14	910
UpSE of US	Linear	6	155	530	Spherical	17	210	687
BsSE of US	Linear	6	228	530	Spherical	17	350	719
MC (%) of US	Exponential	13	70	480	Gaussian	26	41	580
AC (%) of US	Gaussian	13	50	1150	Gaussian	10	70	320
LCV(kcal/kg) of US	Exponential	10000	288936	400	Gaussian	30000	109731	320
Thickness of LS	Spherical	2	12	870	Gaussian	1	9	926
UpSE of LS	Linear	6	309	450	Spherical	6	402	620
BsSE of LS	Linear	6	350	450	Spherical	6	380	620
MC (%) of LS	Spherical	3	23	714	Gaussian	7	37	410
AC (%) of LS	Gaussian	10	31	764	Spherical	3	27	480
LCV(kcal/kg) of LS	Exponential	10000	69433	836	Spherical	120	569395	510

Note: *US: Upper Seam, LS: Lower Seam, UpSE: Upseam Surface, BsSE: Bottomseam Surface.

Table 2b. Semi-variogram parameters of upper and lower seams of fields.

Variable	Hamal Field				Etyemez Field			
	Model	Nugget Effect (C_o)	Sill (C)	Range (A), m	Model	Nugget Effect(C_o)	Sill (C)	Range (A), m
Thickness of US	Gaussian	2	33	454	Gaussian	1	29	787
UpSE of US	Spherical	10	200	675	Spherical	2	500	1000
BsSE of US	Spherical	20	126	640	Spherical	2	580	1000
MC (%) of US	Spherical	2	48	550	Gaussian	1	25	1300
AC (%) of US	Gaussian	25	97	645	Gaussian	1	21	1150
LCV(kcal/kg) of US	Gaussian	21500	215605	330	Gaussian	90000	980638	1060
Thickness of LS	Gaussian	3	17	757	Gaussian	2	19	875
UpSE of LS	Linear	2	60	450	Gaussian	24	123	558
BsSE of LS	Linear	2	72	496	Spherical	24	491	817
MC (%) of LS	Spherical	1	6.8	250	Gaussian	10	115	615
AC (%) of LS	Spherical	1	17.5	250	Spherical	1	20	921
LCV (kcal/kg) of LS	Spherical	30000	148840	250	Gaussian	40000	451911	502

Note: *US: Upper Seam, LS: Lower Seam, UpSE: Upseam Surface, BsSE: Bottomseam Surface.

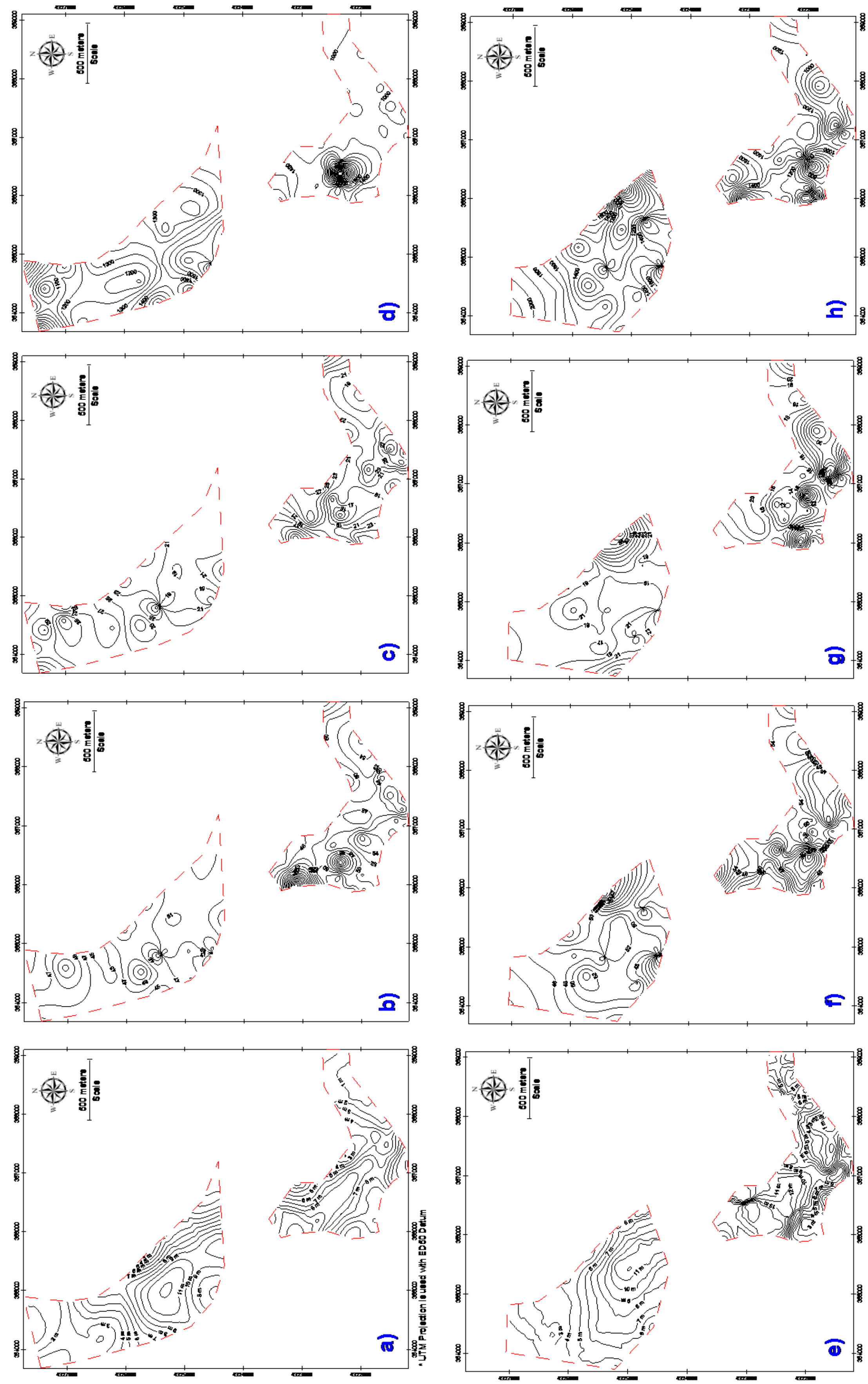

Figure 4. Lignite thickness and quality distribution maps of Kalburçayırı field: a) Thickness of LS, b) MC% of LS, c) AC% of LS, d) LCV (kcal/kg) of LS, e) Thickness of US, f) MC% US g) AC% US, h) LCV (kcal/kg) US.

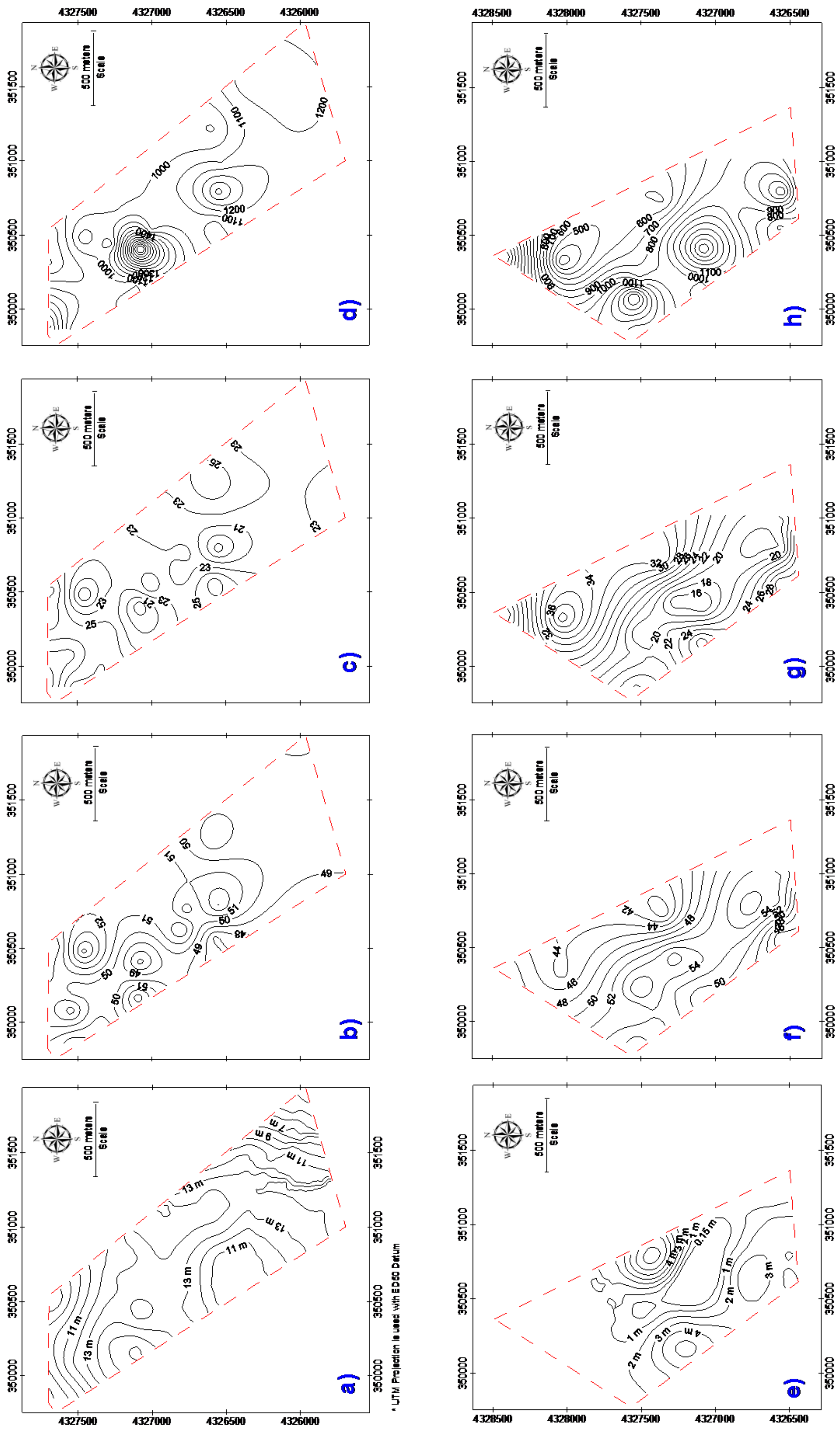

Figure 5. Thickness and quality distribution maps of Etyemez field: a) Thickness of LS, b) MC% of LS, c) AC% of LS, d) LCV (kcal/kg) of LS, e) Thickness of US, f) MC% US g) AC% US, h) LCV (kcal/kg) US.

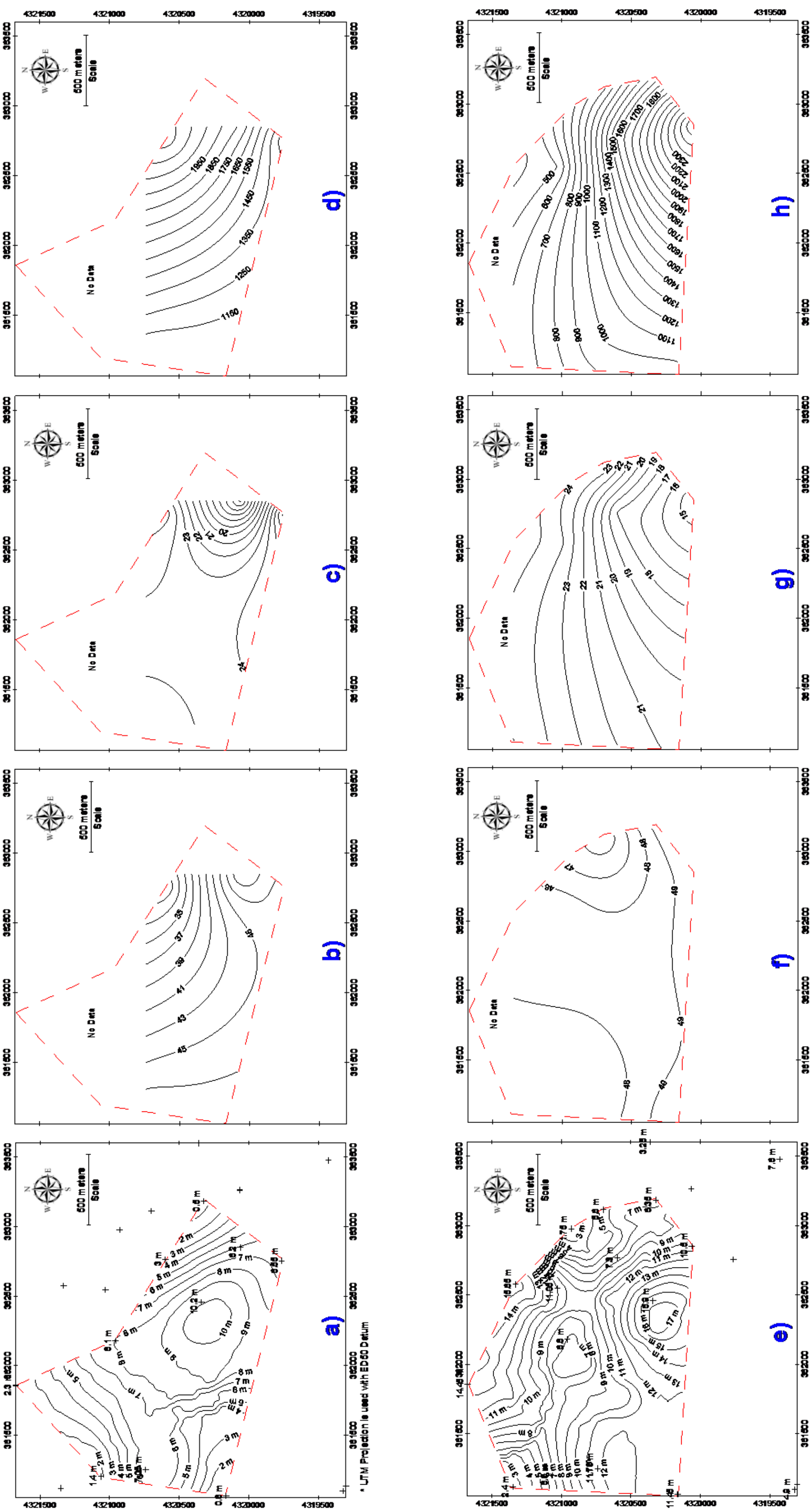

Figure 6. Thickness and quality distribution maps of Hamal field: a) Thickness of LS, b) MC% of LS, c) AC% of LS, d) LCV (kcal/kg) of LS, e) Thickness of US, f) MC% US g) AC% US, h) LCV (kcal/kg) US.

Table 3. Structure of table of integrated estimation results.

Block ID	Eastern (X)	Northern (Y)	Elev. (Z)	LCV	LCV Std. Err.	AC%	AC% Std. Err.	MC%	MC% Std. Err.
1	325150	4243650	968.75	1233.00	139.30	12.69	6.49	52.88	7.35
2	325250	4243650	968.75	1233.00	145.04	12.69	7.39	52.88	7.58
3	325350	4243650	968.75	1220.67	142.10	12.31	7.09	50.76	7.20
¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
2938879	332950	4247450	1226.25	903.40	38.50	23.39	4.94	56.89	2.26
2938880	333050	4247450	1226.25	905.73	57.12	23.39	6.04	58.15	3.26

Note: *LCV: Lover Calorific Value, AC%: Ash Content, MC%: Moisture Content.

In order to determine the lignite resources with different categories, firstly, the coalfield boundary polygons were defined on the computer screen. While defining the polygon boundaries shown in Figures 4-6, only the lignite-containing borehole locations were merged. Therefore, the resources to be estimated were known "measured resources" according to the USGS coal resource classification system [15]. In the second stage of the estimate, query tables related to total lignite volumes and quality values within these polygon boundaries were generated in GIS. Thus thematic maps of the tables obtained were prepared, statistics within the field boundaries were questioned, and the following conclusions were obtained related to the field-based quality and quantity distribution. In a similar way, the cut/fill queries and analyzes were conducted through upper and lower surfaces of each lignite seam and the existing land use maps of the basin, and the overburden volumes to be excavated within the pre-determined polygons were determined and tabulated in Table 4.

In another query, the lignite resource, which could be directly fired without blending process in the power plant, was calculated. In these conditional queries performed on the Hamal and Etyemez databases, the criteria given in Table 5 were considered, and the results obtained were tabulated in Table 6.

Table 4. Measured lignite resource and mean of quality of coalfields.

Defined Polygon		Variable	Upper Seam	Lower Seam	Sub - Total	Overburden from US to Surface
Kalburçayırı	Northern Sector	Resource, m^3	25,657,140.7	28,408,010.3	54,065,151.0	70,549,672.3
		Resource, ton	30,788,568.9	34,089,612.3	64,878,181.2	
		Thickness, m	6.41	6.17		
		MC (%)	47.77	48.25		
		AC (%)	20.05	23.45		
		LCV(kcal/kg)	1421.04	1300.96		
	Southern Sector	Resource, m^3	25,248,366.7	17,733,499.2	42,981,866.0	25,497,602.9
		Resource, ton	30,298,040.1	21,280,199.0	51,578,239.2	
		Thickness, m	7.90	5.43		
		MC (%)	49.72	49.10		
		AC (%)	20.14	21.38		
		LCV(kcal/kg)	1159.35	1281.84		
Hamal Field		Resource, m^3	2,817,087.0	22,252,287.0	25,069,374.1	21,218,408.8
		Resource, ton	3,380,504.5	26,702,744.4	30,083,248.9	
		Thickness, m	1.86	12.26		
		MC (%)	49.80	50.11		
		AC (%)	24.96	23.15		
		LCV(kcal/kg)	907.22	1124.45		
Etyemez Field		Resource, m^3	13,346,828.8	26,919,823.4	40,266,652.2	134,623,631.8
		Resource, ton	16,016,194.5	32,303,788.1	48,319,982.7	
		Thickness, m	10.30	6.30		
		MC (%)	48.15	42.82		
		AC (%)	21.21	23.00		
		LCV(kcal/kg)	1157.30	1526.19		

Note: *US: Upper Seam, LS: Lower Seam, Density 1.2 tonne/m^3.

Table 5. Quality of original lignite that could be fed into power plant.

Calorific Value	AC%	MC%
1050 ± 100 kcal/kg	% 8-24	% 50-65

Table 6. Measured lignite resource that could be directly burned in power plant.

Defined Polygon	Resource (tonnage*)	LCV (kcal/kg)	MC%	AC%
Hamal + Etyemez	54,125,080	1125.89	46.52	22.59

Note: *Lignite Density 1.2 tonne/m^3.

5. Conclusions

In this work, the quantity and quality estimations of lignite in Pliocene-aged Kangal basin were examined. The lignite deposit in the basin consists of two seams, as lower and upper. The thickness between two seams changes between 3 and 33 m in the Hamal field, 4 and 25 m in the Kalburçayırı field, and 5 and 40 m in the Etyemez field. The thickness of lignite seams changes between 0.10 and 18.25 m in the Hamal field, 0.50 and 16.90 m in the Etyemez field, and 0.10 and 16.10 m in the Kalburçayırı field. The coal series that is 60 m long in the Hamal field becomes thinner towards North and disappears. The same situation is also observed in the Kalburçayırı and Etyemez fields. The coal series that reaches up to 80 m in the Kalburçayırı field becomes thinner towards North and Northeast and disappears.

It was estimated that the total lignite resources of the Kangal basin were 194,859,652.00 tons. In the lignite basin, the Kalburçayırı field has a tonnage 116 Mt of lignite with a LCV of 1308 kcal/kg, the Hamal field has a tonnage 30 Mt of lignite with a LCV of 987 kcal/kg, and the Etyemez field has a tonnage 48 Mt of lignite with a LCV of 1282 kcal/kg.

In a query performed in order to estimate the total lignite that can be fed to the power plant directly, it was calculated that almost 24,278,151 tons of lignite in the Hamal and Etyemez fields had a quality of less than 950 kcal/kg. In order to evaluate these low quality lignites economically, they have to be mixed with high quality lignite from the Kalburçayırı field. As a result, in terms of efficient source usage, the Hamal and Etyemez fields should go into production as soon as possible and be fired in the power plant after being mixed with the lignite in the Kalburçayırı field so that they can be redounded to economy.

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ارزیابی ذخیره با استفاده از GIS در حوضه زغال‌سنگی Kangal در استان Sivas کشور ترکیه

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چکیده:

در این پژوهش، با استفاده از مدل بلوکی و به کمک GIS به تعیین تناژ و عیار در حوزه زغال‌سنگی Kangal پرداخته شد. در مرحله اول، تمام نمودارهای سنگ‌شناسی گمانه‌های حفاری و داده‌های آنالیز شیمیایی مغزه‌ها در این حوضه زغال‌سنگی با کمک روش زمین‌آماری آنالیز شدند و سپس نقشه‌های تصویر دیجیتال هر یک از مشخصه‌ها مانند ضخامت، ارزش حرارتی، خاکستر محتوی، رطوبت محتوی و نقشه‌های سطحی از لایه‌های لیگنیت در محیط GIS ترسیم شدند. در مرحله دوم، مقادیر روباره و ذخایر با روش‌های مختلف بر اساس کیفیت و حجم ذخایر با کمک نقشه‌های دیجیتال در GIS محاسبه شد. طبق نتایج تخمین زده شد که ناحیه زغال‌سنگی Kalburçayırı دارای ۱۱۶ میلیون تن لیگنیت با ارزش حرارتی ۱۳۰۸ کیلوکالری بر کیلوگرم، ناحیه زغال‌سنگی Hamal دارای ۳۰ میلیون تن لیگنیت با ارزش حرارتی ۹۸۷ کیلوکالری بر کیلوگرم و ناحیه زغال‌سنگی Etyemez دارای ۴۸ میلیون تن لیگنیت با ارزش حرارتی ۱۲۸۲ کیلوکالری بر کیلوگرم هستند. همچنین تخمین زده شد که تقریباً ۲۴/۲۷۸/۱۵۱ تن لیگنیت از نواحی زغال‌سنگی Hamal و Etyemez دارای ارزش حرارتی کمتر از ۹۵۰ کیلوکالری بر کیلوگرم هستند که می‌توانند مستقیماً بدون فرآیند ترکیب در نیروگاه سوزانده شوند. به عنوان نتیجه‌ای دیگر از این کار پژوهشی مشخص شد که نواحی زغال‌سنگی Hamal و Etyemez باید در اسرع وقت به مرحله تولید برسند و پس از ترکیب شدن با لیگنیت ناحیه Kalburçayırı در نیروگاه سوزانده شوند تا بتوانند در چرخه اقتصادی کمک شایانی داشته باشند.

کلمات کلیدی: حوضه زغال‌سنگی Kangal، GIS، زمین‌آمار، تخمین ذخیره.