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# Computer Aided Coal Seam Modeling for Resource Estimation

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**Abstract:** The Badin Coal Field (BCF) is well-known for the availability of considerable coal resources. The estimation of coal resource by Bore Hole Influence Method (BHIM) is an old technique which needs to be replaced by computer aided approach for reliable estimation of natural commodity. The computer aided modeling for the quantification of coal resource has not been conducted yet, particularly for BCF, block-I. The major limitation of conventional resource estimation technique (i.e. BHIM) is a high level of uncertainty due to the ignorance of spatial continuity of the seam thickness and estimation of coal resource into tonnages instead of volume. In this study, an interpolation method named as the Inverse Distance Weighting Method (IDWM) has been used to estimate the coal resource in volume ($m^3$) and to generate spatial distribution maps for various coal quality parameters using basic drill-hole database into the computer aided software Geovia-Surpac. The 3-Dimensional coal seam model has an estimated volume of 18.689 million $m^3$. The spatial distribution maps of coal seam show the increase in moisture content from north-east (35-37%) toward south-west (38-39%) with a negligible variation in moisture content of coal seam. The Gross Calorific Value (GCV) is homogeneously distributed with an average GCV (3750 k. Cal/kg), except in southern block. The sulfur content of coal seam located in the south-west is less than the sulfur content from north-east. This study provides an insight for the policy makers to consider the spatial maps of coal seam for the mine-plan and operation.

**Keywords:** Resource Estimation, 3-D Geological modeling, Coal Quality Parameters, Inverse Distance Weighting Method

## 1 Introduction

Resource estimation techniques play an important role to decide the economic worth of a mineral deposit during the development and exploitation phases of mine [1]. The overestimation and underestimation of mineral deposit could lead to create the problems during mine operation-plan [2-4]. Reliable resource and grade estimation helps in economic evaluation of the mineral deposits [5]. The appropriate knowledge of resources increases the confidence level in defining potential coal reserves [1, 6]. 3-D modeling is a modern technology for estimating mineral resources and determining surface and sub-surface properties of the deposit both quantitatively and qualitatively. The 3-D coal seam models shows that how the 3D geological figures and maps can be used to understand that how the coal seam thickness and structures are changing on a small scale [7]. Such kinds of model are mostly constructed using drilling data, geologic mapping, and survey records of structural data [8-10]. The coal quality parameters (calorific value, ash, moisture contents, volatile matter, and sulfur) must be estimated in the block model if a consistent seam model is generated [11]. Computer aided modeling is faster and more reliable. The updating of data and adding the new information is simple and quicker [12]. Reliable resource estimation can only be obtained using specific interpolation techniques that will increase the accuracy [13].

To generate solid model and estimate resources various studies have been carried out for comprehensive mining and financial decisions. Qu et al. (2022), modeled different geological features of uranium mine and predicted the reserves-related parameters using eight different interpolation methods in order to know the accuracy of different interpolation approaches [5]. Lignite reserves were determined and modeled by Uyan and Dursun (2021) for generating spatial maps using geostatistical analysis and GIS [14]. Liu et al. (2021) suggested a new Inverse Distance Weighting (IDW) approach after comparing the results of adoptive IDW with classical IDW and improved IDW for enhancing the accuracy of large-scale 3D geological models [15]. Bargawa and Tobing (2020), estimated the grade of an iron ore mine by means of ordinary kriging, inverse distance weighting, and nearest neighbor polygon method in order to evaluate the reliability of each method in iron ore resource estimation [16]. 3D geological modeling of Tongshan Cu mine, China, was performed to calculate the mineral resources [8]. Sonda-Jherruck coalfield of Pakistan was modeled by Jiskani et al. (2018) to estimate the coal resources and develop spatial distribution map of seam thickness map using Surpac software [10]. Huang and An [17] performed geostatistical modeling using Surpac software to calculate the ore volume and generated grade-tonnage curves for future mining activity. Sahoo and Pal [18] built a Bauxite ore model geologically using Surpac software, and grades of different constituents were determined by the Inverse Square Distance Method (ISDM). Siddiqui, et al. [19] calculated the coal resource of the main coal seam at Thar by section method and generated spatial maps of various coal quality attributes using the ordinary kriging approach. Moharaj and Wangmo [20] computed the ore reserves of an iron ore mine in India by means of 3 approaches (nearest neighbor method, inverse distance weighted power 2 and 3 approach, and ordinary kriging method). Tercan, et al. [21] constructed a 3D coal seam model of Eynez Soma and Omerler Tuncbilek coalfields to determine the coal resources. Ertunç, et al. [22] estimated different coal quality parameters of a lignite deposit subjected to severe tectonic movement using different geostatistics approaches. The iron ore mine at Barsua was modeled b [23] and ore reserves were estimated using Surpac software. Huang, et al. [24] established a Surface model, ore body model, development system model, and block model of lead

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and zinc mine of Arhada to calculate the reserves and evaluate the grade of lead, zinc, and silver using Distance Power Inverse Ratio Method (DPIRM). 3D geological model which includes fault wireframe model, terrain model & coal and rock-solid model was built and compared with traditional methods. A block model was also built to calculate the mining and stripping quantities [13]. Modeling of coal deposit in N-W Greece was conducted to evaluate the lignite resources [25]. Coal quality parameters of a multi-layer coal resources were evaluated with 3 geostatistics approaches (ordinary kriging, co-kriging, and functional-kriging) by [26, 27]. 3D geological modeling of surface, ore deposit, cavity, fault, and underground openings were constructed. The volume of ore body and grades of lead, Zinc, and tin were estimated using ordinary kriging method and their grades were compared to original prospecting results [28]. 3D subsurface modeling was done at Handeresi metal mine using Inverse Distance Weighted (IDW) interpolation for ore grade estimation and kriging for surface modeling. An intense vegetated area with irregularly and insufficient boreholes was targeted. Three ore zones were seen intensively [29]. A simple approach called the horizons method was presented for generating a Solid model [30]. Coal zones of heterogeneous formations were interpolated and simulated for evaluating the coal resources and reserves [31]. Geostatistical modeling of High Phosphorous (HP) stockpile at iron mine of Iran was performed to evaluate the reserves and grades using ordinary kriging method [32].

The coal resource of BCF, block-I were estimated using Bore Hole Influence Method (BHIM) of USGS coal resource classification standard. Computer aided modeling for quantification of coal resources has not been conducted yet. The major limitation of previous resource estimation technique is a high level of uncertainty due to ignorance of spatial continuity of seam thickness. This study aims to generate solid model and block model to estimate the coal resource of coal seam using drill-hole database in the computer-aided software Geovia-Surpac and to develop spatial distribution maps for various coal quality parameters using an interpolation method, Inverse Distance Weighted Method (IDWM).

## 1.1 Inverse Distance Weighting Method (IDWM)

IDWM is an interpolation technique used for estimating the unknown value by known values. The unknown values are more or less influenced by the values which are closer to them. The IDWM takes the known points and create the surface by estimating unknown points. IDWM relies on the inverse of distance raised to a mathematical power. The higher the power the more influence on nearest point [33]. The mathematical formula of IDW is shown in Equation 1.

$$W_p = \frac{\sum_{i=1}^{n} \frac{W_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}} \qquad (1)$$

where, $W_p$ is estimated weight at unknown point, $W_i$ is the weight of known point (measured location) and $d_i$ is the distance between the location of known value and unknown value, p is the power value.

### 1.1.1 Considerable Parameters of IDWM

- Power Value: The power in IDWM play a significant role for predicting the values at unknown locations. With the increase of power value, the influence of nearest value increases on predicted location and the influence of known value which are far from unknown value decreases [33]. By increasing the power, the maps become so detailed and values are assigned in polygonal way that is the established power for geological deposits.
- Search radius: By specifying the search radius only those points will be used by the interpolation which lie within the search radius. With the increase of search radius, more points are included for predicting the unknown values.

## 1.2 Badin Coal Field (BCF)

BCF was discovered by Geological Survey of Pakistan (GSP) in 2005. Almost 850 million tons of coal resources in the BCF

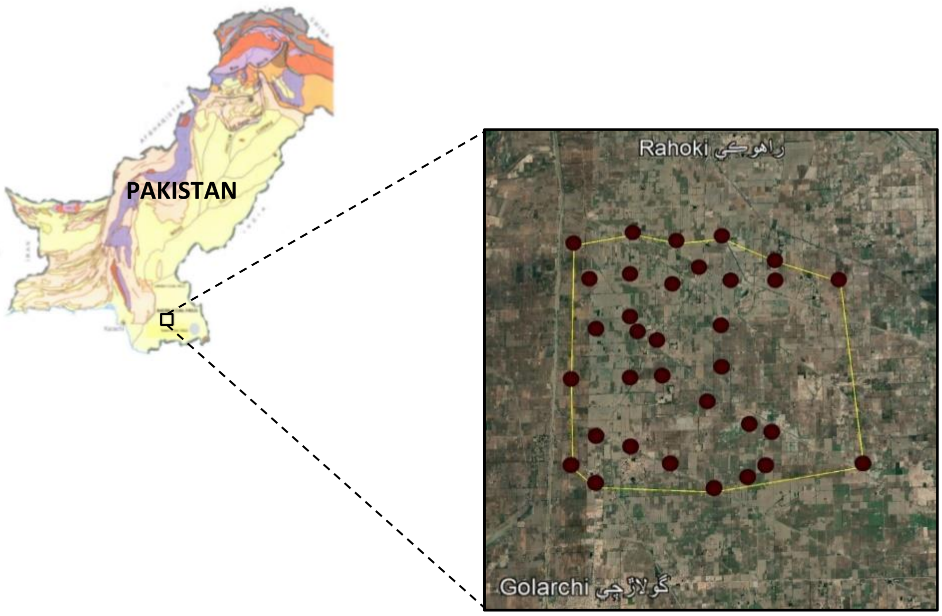


**Figure 1. Location, boreholes and boundary of BCF, block-I**

with coal thickness ranging between 0.55 to 3.1 meters were informed by GSP [34]. The review of data of holes drilled by GSP, Sindh Coal Authority, and drilling by Al-Abbas Group indicated the presence of six shallow coal beds on the western side of BCF. The detailed exploration of about 50% of 100 sq. km granted to Roadways Pakistan (Pvt) limited as reconnaissance license has been carried out by Al-Abbas group in august 2007. Table 1 shows the lithology of BCF, block-I and Figure 1 shows location map presenting boreholes and boundary of BCF, block-I.

## 2 Materials and Methods

### 2.1 Exploratory data analysis

The exploratory data of thirty-three boreholes drilled by Al-Abaas group in 2007 was collected and examined in order to create a high-quality database. The obtained data includes collar information, lithological data, and coal quality attributes. The average, minimum, and maximum recorded depth of boreholes was 109.72 m, 251.76 m, and 180.74 m respectively. The average borehole spacing was calculated as 1200 m. The summary of drill-hole information is shown in Table 2. The collected coal quality data includes Moisture Content (MC), Ash, Gross Calorific Value (GCV), and Sulfur on as received basis. Six coal beds have been encountered in the boreholes. In this study, the coal resources of only one coal seam have been estimated because of the availability of limited data. The coal seam data is shown in Table 3. After initial assessment of digital data, the entire dataset including collar co-ordinates, drill-holes depth, survey records and lithology codes were reviewed and validated in the database. After reviewing the data, a complete digital database that includes all geological data and quality parameters was generated for generating solid and block model.

### 2.2 Geological Modeling procedure

3-D geological models are the picture-based view of sub-surface formations and the features related to them [35]. The geological model presents a base for evaluating, estimating and calculating the coal reserves according to established resource evaluating standards. Two models (solid and block model) are generated for this study.

**Table 1 Lithology of BCF, block-I**

| Formation and age | Thickness (m) | Lithology |
|---|---|---|
| Alluvium (recent) | 50-95 | Silt, clay, and sand. |
| Sub-recent formation | 20-50 | Sandstone, siltstone, and claystone. |
| Bara formation (Paleocene) | >230.30 | Sandstone, carbonaceous claystone, and coal |

**Table 2 Summary of drill--hole information**

| No. of drillholes | Average DS[1] (m) | Depth of drillhole (m) | | |
|---|---|---|---|---|
| | | Min[2] | Max[3] | Avg[4] |
| 33 | 1200 | 109.72 | 251.76 | 180.74 |

Note: [1]Drillhole Spacing, [2]Minimum, [3]Maximum, [4]Average

**Table 3 Summary of coal seam**

| Presence in BH[1] out of 33 | Thickness (meters) | | |
|---|---|---|---|
| | Min[2] | Max[3] | Avg[4] |
| 05 | 0.3 | 6.2 | 2.09 |

Note: [1]Borehole Spacing, [2]Minimum, [3]Maximum, [4]Average

**Table 4 Tables and fields used in Surpac**

| Table | Collar | Survey | Lithology |
|---|---|---|---|
| Fields | hole Id | hole Id | hole Id |
| | Northing | Depth | sample start points |
| | Easting | northing | sample end point |
| | Elevation | easting | rock type |
| | Depth | elevation | seam code |
| | n/a | Dip | n/a |
| | n/a | azimuth | n/a |

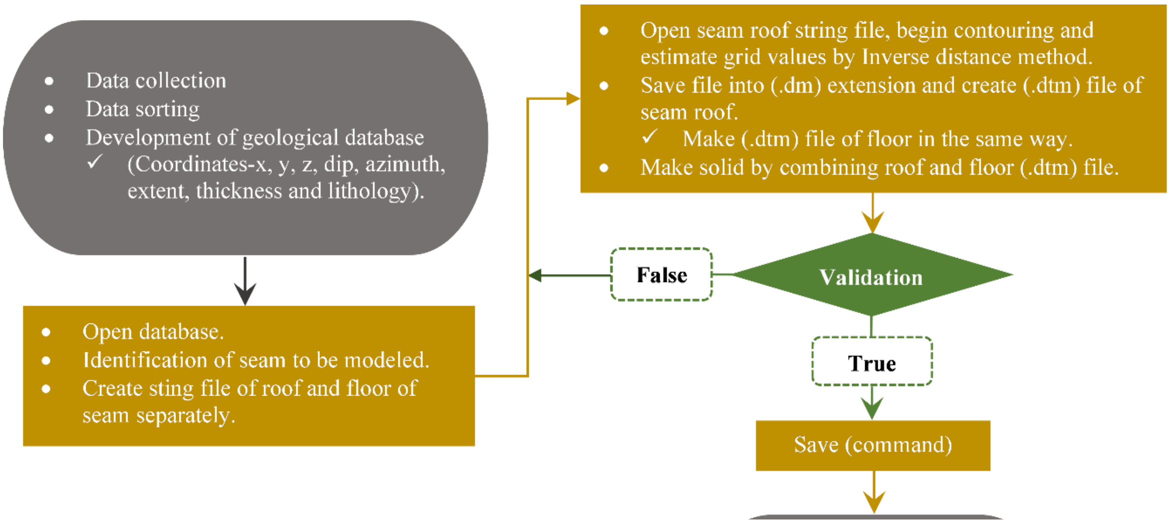


**Figure 2. Process used to generate solid model through Surpac**

### 2.2.1 Solid modeling

Solid modeling is a computer-aided modeling of an objects in which data is triangulated using two methods known as top to bottom surface method and section method. In the section method, the vertical sections of the coal seam are created and triangulated to produce a 3-D solid seam model whereas in the top to bottom surface method, the model is generated by triangulating and interpolating the top and bottom of the seam. Finally, the top and bottom surface of seam is combined to produce a 3-D solid seam model [10, 11, 19]. In this study top to bottom surface method was used to produce a 3-D solid seam model in the computer-aided software Geovia-Surpac 6.6.2. The structural simplicity of seam caused to use the top to bottom surface method for creating the solid model. Geovia-Surpac is a user-friendly and registered software in the department of Mining Engineering. The software contained multiple options for modeling. A digital geological database is used to create a model. Two compulsory tables (collar and survey table) which contains various fields are the basic for modeling. Whereas, optional tables are also used for different purposes. In this study, two optional tables (geology and survey table) were used. Tables and fields used in Geovia-Surpac for generating 3D geological modeling are shown in Table 4. After generating the solid model, the volume of coal seam model was calculated which is automated in Geovia-Surpac by using OBJECT REPORT (OBJREP) command. The command used will generate a file reporting the volume of coal seam. Figure 2 shows the process used to generate a solid model through Surpac.

### 2.2.2 Block modeling

In this study, the constructed 3-D solid seam model was divided into a series of blocks having dimension 250 m × 250 m × 0.5 m keeping in view the thickness of coal seam and the average drill-hole spacing. Block model was created in the computer aided software Geovia-Surpac. After generating the block model, a constrained coal seam model was created from solid seam model (.dtm). The constrained model was used to generate the spatial maps of coal seam. The constrained model was filled with coal quality parameters values using an interpolation method IDWM for estimating the values in whole seam. After filling the block model properly, a command Block Model Graphics Attribute Colour (BMGAC) was used to generate the spatial map.

## 3 Results and discussion

For estimating the coal resources available in coal seam, a non-conventional method that uses Surpac 6.6.2. was used. First of all, a digital geological database was generated which is the foundation of all geological modeling. After that the coal resources were estimated by generating a solid seam model. 3D solid seam model was used to generate a block model in order to develop the spatial distribution maps. The minimum depth of coal seam was found as 113 meters below the surface. The maximum thickness of coal seam is 6.2 meters which is encountered in only one borehole. The coal seam model estimated a volume of 18.689 million m$^3$. Figure 3 a, b, c, and d shows the spatial distribution maps for Moisture Content (MC), Ash, Gross Calorific Value (GCV), and Sulfur respectively. The spatial distribution maps of coal seam show the increase in moisture content from north-east (35-37%) toward south-west (38-39%) with a negligible variation in moisture content of coal seam. The ash content of coal seam increase from west toward east. The Gross Calorific Value (GCV) is homogeneously distributed with an average GCV (3750 k. Cal/kg), except in southern block. The sulfur content of coal seam located in the south-west is less than the sulfur content from north-east.

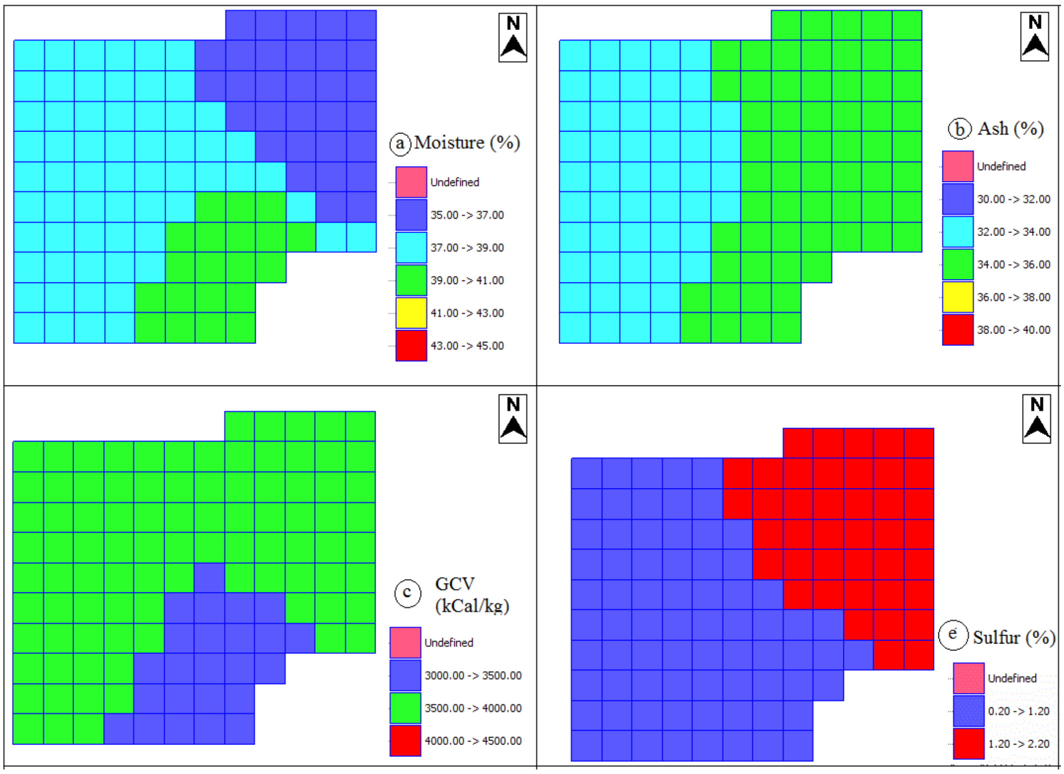


**Figure 3. Spatial maps for various coal quality parameters**

**Table 5 Coal quality parameters from block model estimates**

| Parameter | Moisture Content (%) | Ash (%) | Gross Calorifc Value (K. Cal/kg) | Sulfur (%) |
|---|---|---|---|---|
| Minimum | 36.8 | 33.2 | 3097 | 0.6 |
| Maximum | 40.7 | 35.5 | 3982 | 1.7 |
| Average | 37.90 | 33.72 | 3571.05 | 0.87 |

# 4 Conclusion and recommendations

The computer aided resource estimation methods are modern, fast and time saving as compared to conventional resource estimation methods. The BCF, block-I contained considerable coal resources. The computer-aided modeling regarding to estimate the coal resource has not been conducted. Therefore, this study was aimed to generate solid seam model and to develop spatial distribution maps for various coal quality variables utilizing borehole data in the computer-aided software Geovia-Surpac using an interpolation technique Inverse Distance Weighting Method (IDWM). The coal seam model occupied a volume 18.689 million m3. The spatial distribution maps of coal seam show the increase in moisture content from north-east (35-37%) toward south-west (38-39%) with a negligible variation in moisture content of coal seam. The Gross Calorific Value (GCV) is homogeneously distributed with an average GCV (3750 k. Cal/kg), except in southern block where average GCV content is (3250 k Cal/kg). The sulfur content of coal seam located in the south-west is less than the sulfur content from north-east blocks. This study provides an insight for the policy makers to consider the spatial maps of coal seam for the mine-plan and operation.

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