p-ISSN 2089 – 0133 e-ISSN 2477-6416
URL : https://jurnal.uns.ac.id/ijap/article/view/59295

DOI : https://doi.org/10.13057/ijap.v12i1.59295

3D INVERSION OF GRAVITY DATA MODELING USING THE CHI FACT ALGORITHM FOR REVEALING SUBSURFACE STRUCTURE IN SEMARANG CITY

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Received 11-02-2022, Revised 15-03-2022, Accepted 16-03-2022
Available Online 17-03-2022, Published Regularly April 2022

ABSTRACT

The interpretation of subsurface in the Semarang City with 3D inversion model using the Chi Fact algorithm has been carried out to reveal the subsurface especially related to the presence of groundwater basins. The gravity data model in this research uses 80 stations with a research area of 20 km^2 which is specialized in the surrounding area of Kaligarang district. The results of the 3D inversion using the Chi Fact algorithm founded the distribution of subsurface rock density values in the Semarang City area ranging from 1.6 gr/cc to 2.98 gr/cc. The distribution of subsurface density values indicates the subsurface geological structure of the Semarang City area had a normal fault leading to the southeast.

Keywords: 3D inversion; chi fact; gravity method; semarang.

INTRODUCTION

In the field of geophysics, knowing the subsurface conditions using geophysical methods is very interesting. By examining the subsurface structure of a research area, we can find out the dynamics of the subsurface. In subsurface modelling, there are two modelling methods that are often used, namely forward modelling and inversion modelling. Inversion is often referred to as data fitting, the principle of inversion is to find model parameters that produce a response that matches the data. Inversion is the opposite of forwarding because in inversion the model parameters are obtained directly from the data. Inversion modelling is the process of modifying the model to get a better fit for calculation data and better observational data which is done automatically.[1]

The city of Semarang is the capital of the province of Central Java, which has a large population. Based on BPS data [2] the amount of resident in 2020 in Semarang city are 1,653,524 and the people density is 4,425 people/km^2. Based on the information above, if a disaster occurs, for example, an earthquake, it will be very dangerous for people living in Semarang. Another disaster threat is landslides in the upper part of the city of Semarang.

Several incidents of landslides and land subsidence have occurred in Semarang which caused damage and loss of people's homes. [3,4] in Addition, the absence of information and knowledge of geology in the community causes a minimal understanding of disaster mitigation. The subsurface of Semarang city has some geologic structures, namely major faults and minor faults. The record of fault activity is not much, but it can be a potential for reactivity [5]. Several studies have been carried out but are not continuous so that changes from time to time are not observed in detail.

GRAV3D is one of the tools that can be used to perform forward modeling and inverse modeling of land gravity data, airborne data, and drill hole data in three dimensions. Forward 3D modeling is the gravity response of the vertical component of subsurface rock density in 3 dimensions. The model uses a 3D mesh of square cells with each mesh expressing a density contrast constant. Models can also include topography. The gravity response can be calculated for each mesh in the model volume and topography that simulates gravity data retrieval (land gravity, airborne gravity, or well log)[6-8]. This study aims to examine the subsurface of Semarang City using the gravity method with data processing using the Chi Fact algorithm. The results obtained can be used to assist local governments in the field of mitigation.

METHODS

One of the physical parameters that form the basis of subsurface research is density. Newton's theory describes the action-reaction between 2 masses that are at a certain distance. The distance between objects affects the strength of gravity. The farther away, the weaker the gravity. Density variations affect the value of gravity. The greater the density, the greater the gravity. Density variations vertically and horizontally produce a variety of responses to gravity anomalies on the surface. Gravity modeling is a method used to determine the density variation. Gravity modeling consists of forward and inverse modeling. The inversion modeling process requires an algorithm in the calculation process. Different software uses different algorithms.

GRAV3D adopts more than 1 algorithm in its use. One of the algorithms in GRAV3D is Chi Fact. Chi Fact algorithm validation in the GRAV3D gravity data inversion program was carried out through the initial modeling stages with the MeshTools3D program. the next stage of advanced modeling to obtain the initial model's gravity response. Compilation of synthetic gravity data by adding a Gaussian distributed error to the initial model's gravity response data. The last one is the inversion of synthetic gravity data with the Chi Fact algorithm in the GRAV3D program from determining the lower limit of the recovered model repeatedly until the recovered model is obtained [9].

The inversion problem is formulated as an optimization problem of the global objective function ϕ density of the model. The objective function must have the flexibility to construct a model that approximates the ρ_0 reference model and produces a smooth model in three spatial directions. The next calculation is done to minimize : $\emptyset = \emptyset_d + \mu\emptyset_m$ such that

$\vec{\rho}_{min} \leq \vec{\rho} \leq \vec{\rho}_{max}$ where _min and _min are vectors containing lower and upper bounds on the model values.

The new objective function is given by,

$$\emptyset_{(\lambda)} = \emptyset_d + \mu\emptyset_m - 2\lambda \sum_{j=1}^{M} \left[ln\, ln\left(⊠_j - \rho_j\right) - ln\, ln\left(⊠_j^{max} - \rho_j\right)\right] \quad (1)$$

where λ is the barrier parameter, and the regularization parameter λ is fixed during minimization to produce the optimal recovered model.

Chi fact is a non-positive line search algorithm to find μ_0 which raises $\emptyset_d^*$. This search also results in the slope of the misfit curve s_0 at _μ_0. This process is very efficient and the CPU time required is much shorter than the time required for a solution with positivity. Using the assumption s_0 can be used to estimate the slope of the discrepancy curve when using positivity. A more precise line search through positivity concatenation begins with the initial guess $\mu = 0{,}5\,\mu_0$. This usually results in a mismatch very close to the target value. However, if the mismatch is not close enough to $\emptyset_d^*$, a new guess for μ_0 is obtained using an estimate of the slope of s0. Inversion with update can be solved efficiently if the logarithmic barrier algorithm starts from the initial model which is close to the final solution. The model is obtained by changing the corresponding solution μ that has been obtained previously μ_0. Line searches using this strategy often reach the target $\emptyset_d^*$ after testing two to four values of μ.

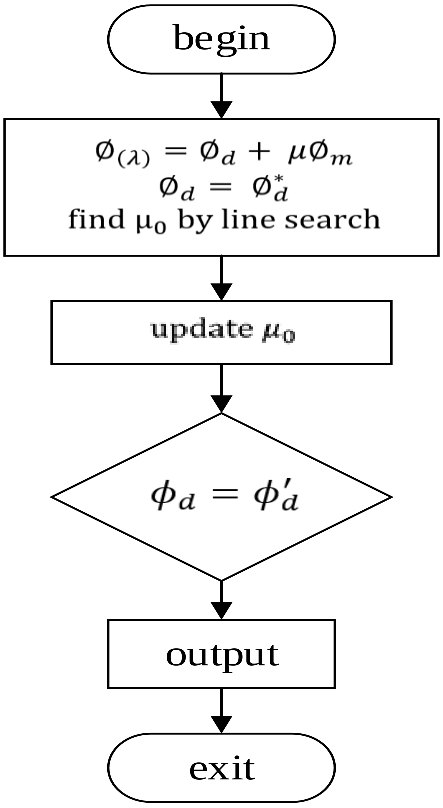

Figure 1. Chi-fact flowchard

Preparation of the initial model using MeshTools3D with the initial model parameters as shown in table 1 and table 2. The initial model parameters are used to produce the initial model as illustrated in Figure 2. The initial model is depicted in the form of 2 ellipsoid balls with different densities, namely 2 and 2.67.

Table 1. Initial model parameters of ellipsoid 1

block	1	
density	2	gr/cm3
type	ellipsoid	
	Coordinates (m)	
X	470	760
Y	200	500
Z	-50	-350

Table 2. Initial model parameters of ellipsoid 2

block	2	
density	2,67	gr/cm3
type	ellipsoid	
	Coordinates (m)	
X	500	800
Y	150	450
Z	-50	-350

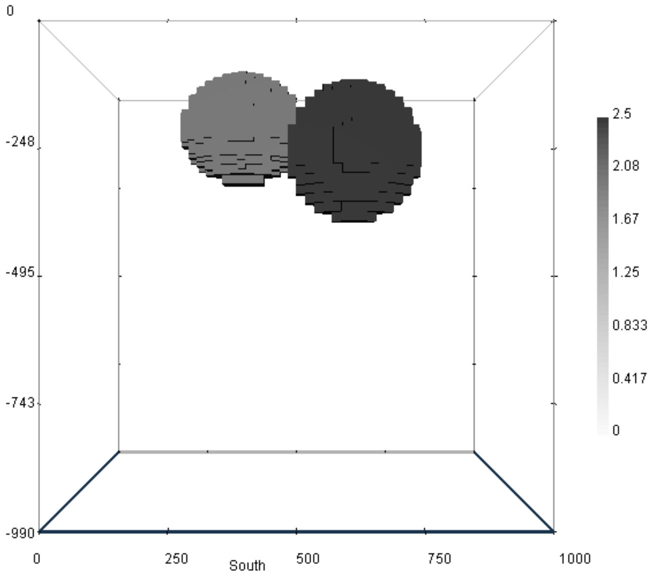

Figure 2. 3D Initial model 3D compiled using MeshTools3d software

The initial model's gravity response was obtained using the gzfor3d.exe program as illustrated in Figure 3.

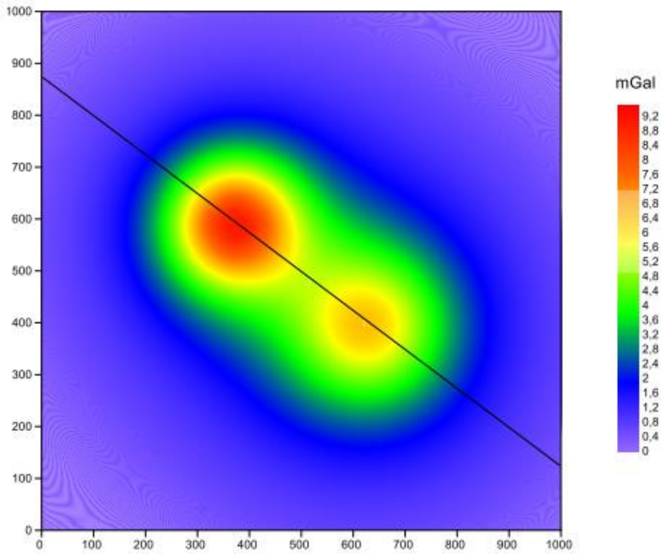

Figure 3. Gravity response of the initial model in 3D compiled using the MeshTools3d software obtained with the gzfor3d.exe program

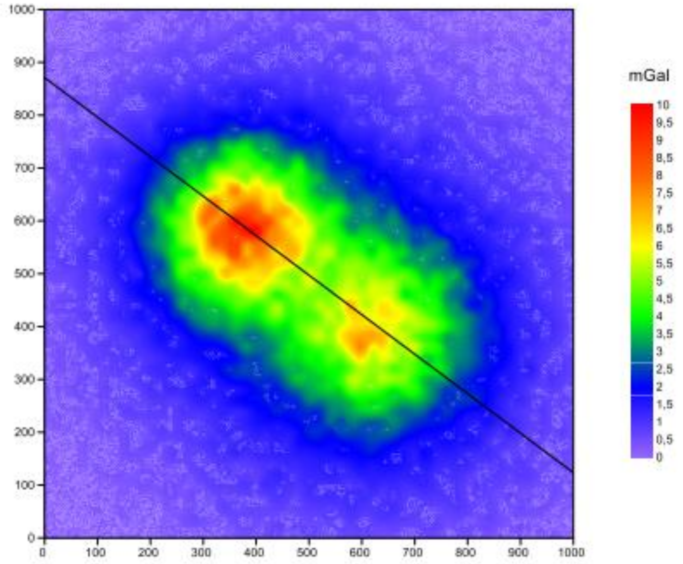

Figure 4. Gravity response of the initial model in 3D compiled using MeshTools3d software obtained with the gzfor3d.exe program which has been added with a Gaussian error of 0.03 mGal.

GRAV3D program validation used the Gaussian method. The following step is the synthetic gravity data is compiled by adding a Gaussian distributed error to the initial model's gravity response data. The gravity response of the initial model was added with a Gaussian error of 0.03 mGal (Fig. 4). Inversion of synthetic gravity data using the Chi Fact algorithm in the GRAV3D program is carried out by determining the lower limit from 10^{-1} to 10^{-12} to obtain the recovered model repeatedly. The recovered model obtained will be smoother [9,10]. The recovered model generated as the final result is depicted in Figure 5.

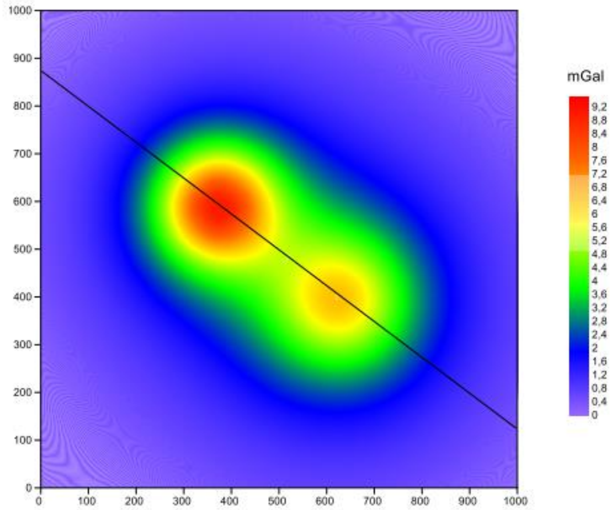

Figure 5. Gravity response of the recovered model in inverted 3D using GRAV3Dsoftware generated for lower bound

The validation results show that the Chi Fact algorithm in the GRAV3D inversion program produces a recovered model that corresponds to the initial model. The conclusion obtained by the Chi Fact algorithm in the GRAV3D inversion program is valid to get used gravity data inversion modeling. The results were obtained with another approach using the Generalized Cross-Validation (GCV) algorithm [6,9,10].

This study uses the case of the city of Semarang. This study uses secondary data on the gravity of the city of Semarang which was acquired by L.M Sabri from the Department of Geodesy, Diponegoro University. This gravity data is part of 2 measurement periods. The research area is located at 6.94° South Latitude to 7.11° South Latitude and 110.51° East Longitude to 110.26° East Longitude (25 km x 15 km). GPS quality control using DEMNAS. DEMNAS is a digital elevation model produced by BIG-Indonesia. Quality control of gravity data was carried out using the correlation method with GGmPlus data, with a correlation value of 0.97 [11]. The software used in data processing is Ms. Excel 2010, Surfer 11, global mapper, Grav3D. Gravity data processing uses secondary data consisting of elevation, position, and gravity observations. The density variation will determine the anomaly value. Density variations produce anomaly values which are the difference between the value of the gravity measurement at a place and the ideal value at that place. The complete Bouguer anomaly is the observation of gravity (gobs) corrected for latitude, density values, and topographic conditions. The correction in the gravity method consists of latitude correction, free air correction, Bouguer correction, and terrain correction. The average density value was calculated using the Parasnis method. The local anomaly is a difference between the complete Bouguer anomaly and the regional anomaly. The local anomaly processing used upward continuation.

Chi Fact algorithm implementation on field data for Semarang and surrounding areas. The selected area of Semarang is about 25 km to the east (X-axis) and 15 km to the north (Y-axis), while the target depth of the model is 7.5 km to the vertical (Z-axis). The length of the X, Y, and Z axes is the size of the major block model (dX, dY, dZ)[12]. The initial model was created using GRAV3D which represents the entire research area. Modeling the initial model, the X-axis is divided into 109 blocks (nx), the Y- axis becomes 67 blocks (ny), and the Z-axis becomes 250 blocks (nz) so as to produce 1,825,750 minor blocks that make up the major blocks as shown in Figure 6, input The Z posit or datum in this initial modeling corresponds to the height of the CBA reduction, which is 500 m

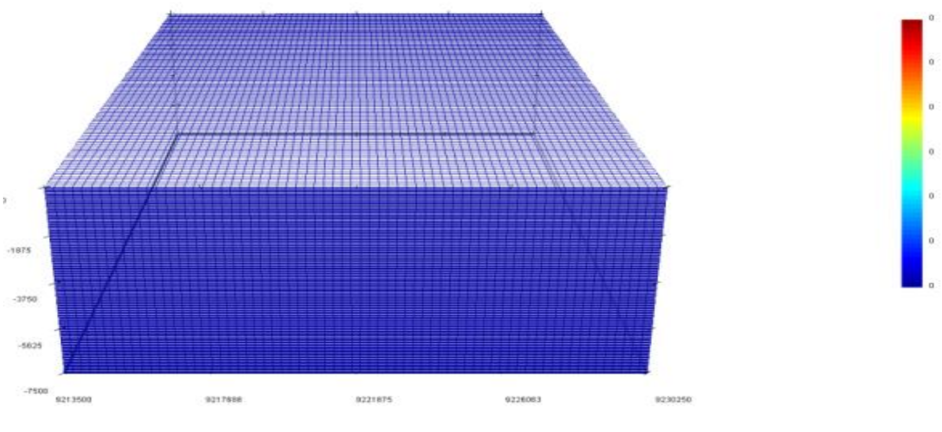

Figure 6. Mesh used as the initial 3D inversion model

RESULTS AND DISCUSSIONS

Bouguer anomaly in the study area is 2 mGal to 22 mGal. The high anomaly is in the east and the low anomaly is in the west (Fig. 7.a.). Local anomalies in the study area are -7 mGal to 6.5 mGal. A high anomaly exists west to east, northeast, and southeast. A low anomaly exists in the southwest (Fig. 7.b.). Figure 7.c. is a map of the elevation of the research area. The hilly area is in the south and the coastal area is in the north. The study area includes hilly and coastal areas (Fig. 7.c.).

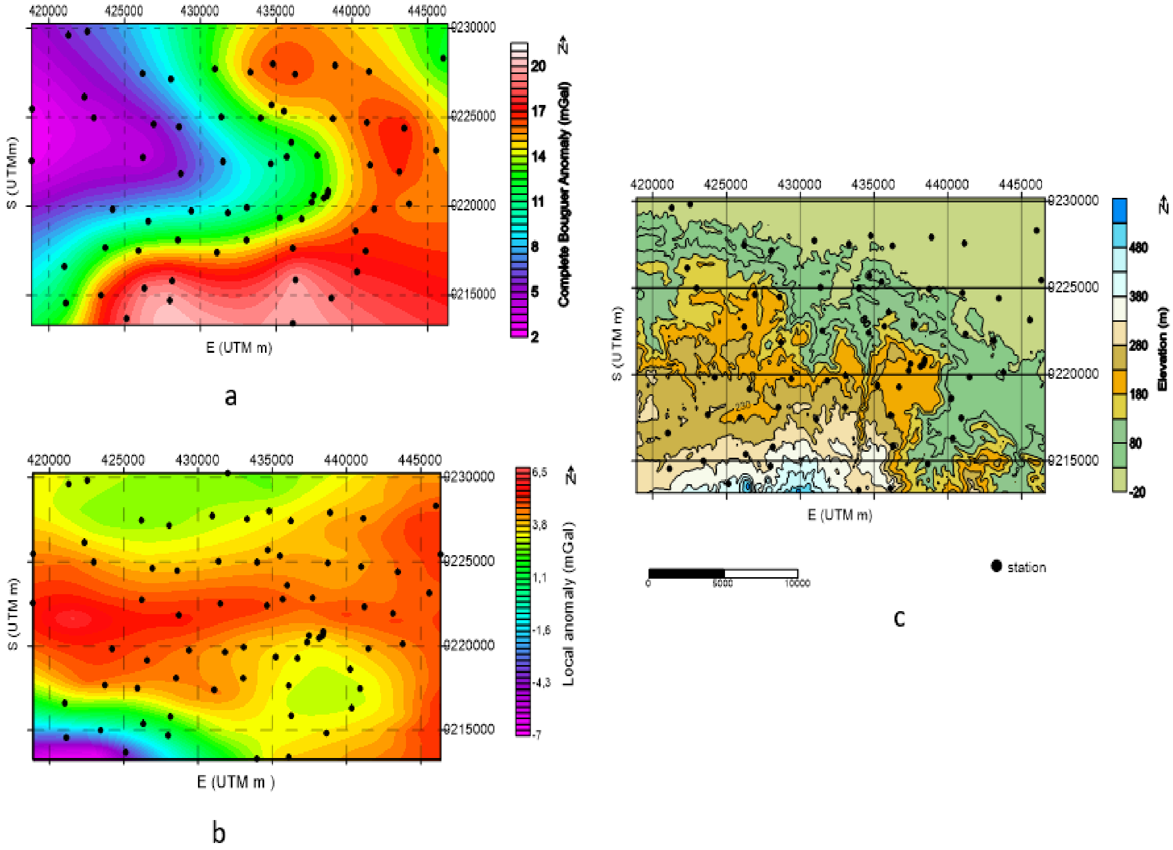

Figure 7. a. Topography map b. Anomali Bouguer map c. topography map

The geomorphology of Semarang City and its surroundings can be grouped into coastal plains, alluvial plains, floodplains, steep slope hills, wavy hills, and highlands. The geology of the city of Semarang is mapped in Figure 8. The geology of the city of Semarang consists of 5 rock formations, namely Damar, Kerek, Kaligetas, Kalibeng, and alluvium. On the geological map, there are faults trending east-west and north-south. Types of rock contained in the formation and density values are listed in Table 3 [14-15].

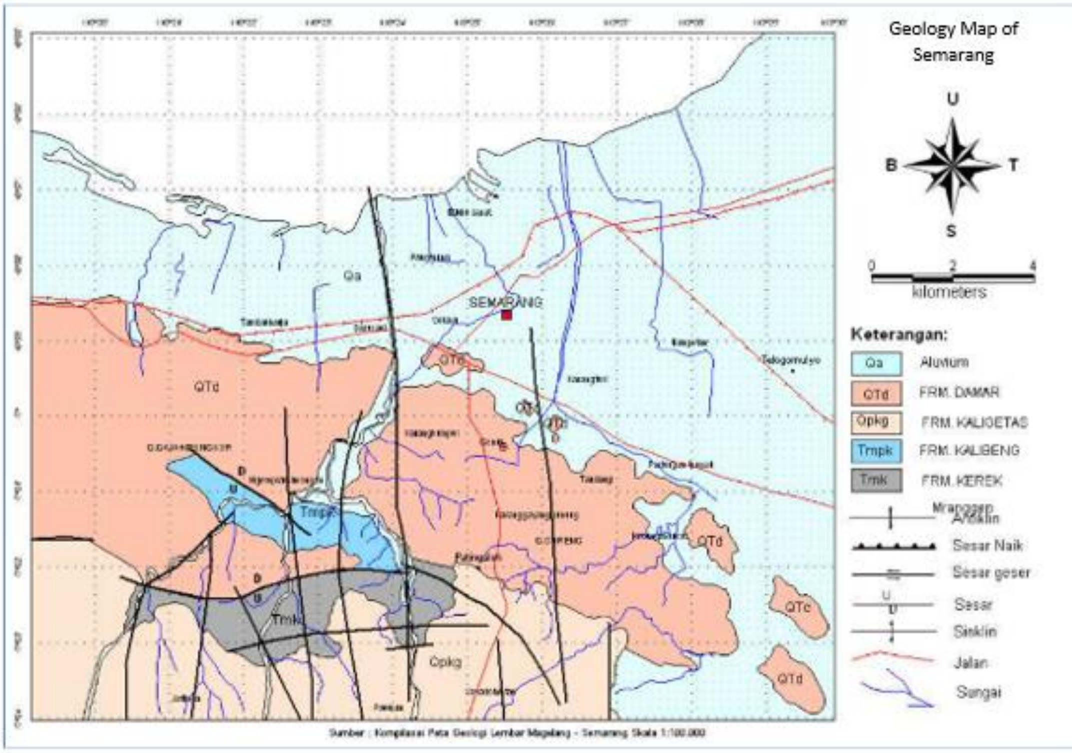

Figure 8. Geology Map of Semarang [11]

Table 3. Rock density

Formation	**Rock type**	**Density from density chart (g/cc) (Telford,1999)**
Kerek (Trnk)	Clay	1.50 - 2.130
	sandstone	2.15 – 2.40
	Volcanic rock	2.70 – 3.30
	limestone	1.50 – 2.70
Kalibeng (Trnpk))	sandstone	2.15 – 2.40
	Volcanic rock	2.70 – 3.30
	limestone	1.50 – 2.70
Kaligetas (Qpg)	tuff	2.59-2.62
	Volcanic rock	2.70 – 3.30
	Andesite - brecia	2.60 – 3.30
Damar (QTd)	sandstone	2.15 – 2.40
	Volcanic rock	2.70 – 3.30
	pumice	0.70 - 1.20
Alluvium (Qa)	alluvium	1.60 – 2.20

Because the research target is not local, the modeling uses complete Bouguer anomaly data. Modeling using grav3d does not have to use local anomalous inputs. Data input depends on the target. Quantitative interpretation through subsurface modeling using GRAV3D and MeshTools, with input in the form of Complete Bouguer Anomaly (CBA) data that has been reduced to a flat plane in the format (*dat) which was created using Surfer software. The inversion performed on the complete Bouguer anomaly data is 7303 with the initial model cell number being 1825750 cells and the mesh being 1825750 cells[13]. line search without positivity with a target of 7303 produces a multiplier value of 0.264060E+02, the norm model is 0.7628E+03 with a misfit of 0.7293E+04 (Table 4).

Table 4. Summary of line search without positivity

Misfit	Model Norm	Multiplier
2,38E+01	3,85E+03	3,43E-04
1,96E+01	3,77E+03	1,72E-03
1,94E+01	3,77E+03	8,58E-03
2,51E+01	3,10E+03	4,29E-02
9,34E+01	2,33E+03	2,15E-01
4,03E+02	1,72E+03	1,07E+00
1,76E+03	1,20E+03	5,36E+00
7,01E+03	7,74E+02	2,52E+01
7,29E+03	7,63E+02	2,64E+01

The Chi factor algorithm implements line search with positivity resulting in a multiplier value of 0.2671E+02, a norm model of 0.7601E+03 with a misfit achieved of 0.7367E+04 which misfit close to the number of data misfit 7360, which means that it is close to the target misfit data (Table 5).

Table 5. Summary of line search with positivity

Misfit	Model Norm	Multiplie r
3,98E+03	9,38E+02	1,32E+01
7,37E+03	7,60E+02	2,67E+01

The cross-section of the modeling from West to East and South to North. On the x-axis, there are 3 cross-sections that are directed West to East. Three incisions were made in the research area stretching horizontally from South to North. This is done to see the subsurface structure of the city of Semarang. The following is an interpretation of the results of 3D inversion modeling using GRAV3D.

Three incisions were made in the research area stretching horizontally from West to East at Y 9125000 m, 9218250 m, 9221500 m. The following is an interpretation of the results of 3D inversion modeling using GRAV3D. The 3D model of the cross-section Y 9215000 m (Figure 9), this incision crosses the Mijen, Gunungpati, and Banyumanik areas, and passes through the Gajahmungkur volcanic rock formations, Kaligesik volcanic rocks, and Kaligetas. The low density in this section occurs because in some areas it is composed of clay and sand with rock densities of 1.63 g/cc to 2.0 g/cc indicated by dark blue to light blue color gradations, these low-density rocks are located along an incision area above the high-density rock, with a depth of up to 5 km below the ground surface. The maximum density in this section is indicated by a yellowish red to dark red color with a density range of 2.73 g/cc to 2.98 g/cc. The density value as in table 1, the rock type is basalt to andesite. The basement rock-like basin at the base of the modeling rises in the west end area, In the middle and east of the incision area, the density value indicates that the area has rock types in the form of basalt lava rock, andesite breccia, and andesite lava[16].

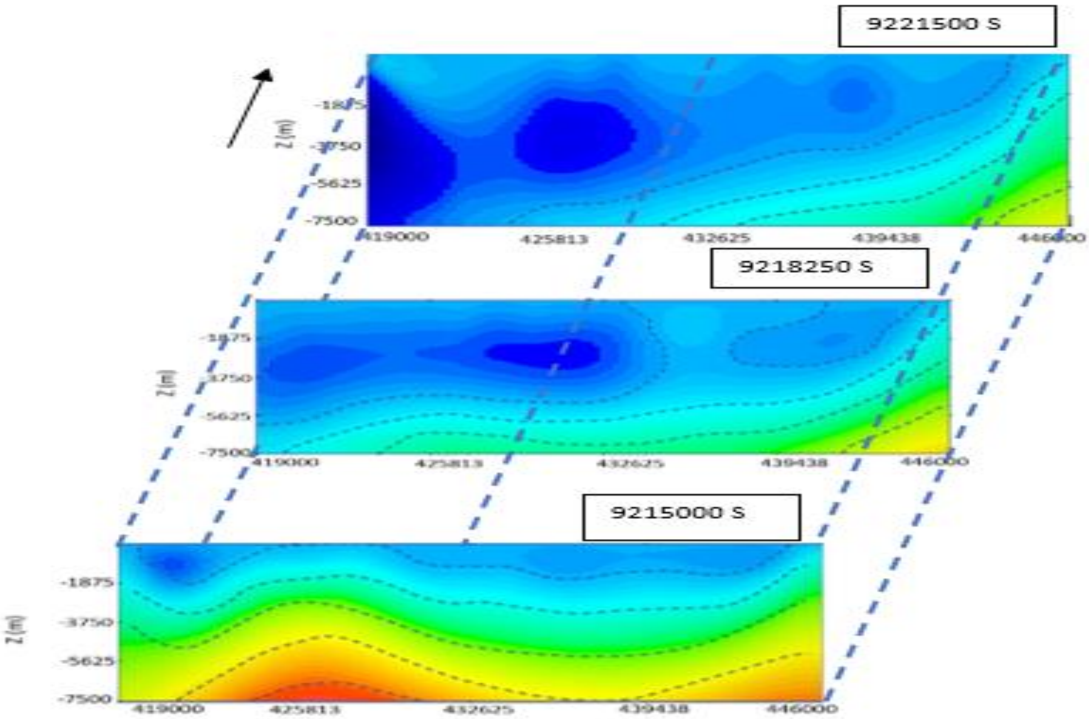

Figure 9. Cross-section AA' on Northing 9215000 3D inversion result

In the 3D model of Y 9218250 m (Figure 9), most of the rock layers in this line are included in Kaligesik rock formations (Table.3). The maximum density in this incision is indicated by a yellowish red to dark red color with a density range of 2.73 g/cc to 2.98 g/cc, with depths ranging from >2 km, the density value indicates if the area has rock types such as andesite, lava, and basalt. The low density in this section is shown in dark blue to light blue with a density range of 1.63 g/cc to 2.0 g/cc, depths of up to 5 km and 3 km, the density values indicate the rock lithology in the form of claystone and sand. The cross-section 9221500 m as shown in Figure 9 slightly crosses the same formation in the middle area of the incision which has the constituent rock of claystone. The maximum density in this incision is indicated by a yellowish red to light-dark red color with a density range of 2.73 g/cc to 2.98 with depths ranging from >2 km, rock lithology in the form of basalt, andesite, and lava rocks. The low density in this section occurs because in some areas it is composed of clay and sand with rock densities of 1.63 g/cc to 2.0 g/cc indicated by dark blue to light blue color gradations. west, east, and middle incision. The depth of low density is deeper on the west side than on the east side [17-20].

Three incisions were made in the research area stretching horizontally from South to North at X 431000 m, 436000 m, 438000 m. The following is an interpretation of the results of 3D inversion modeling using GRAV3D.

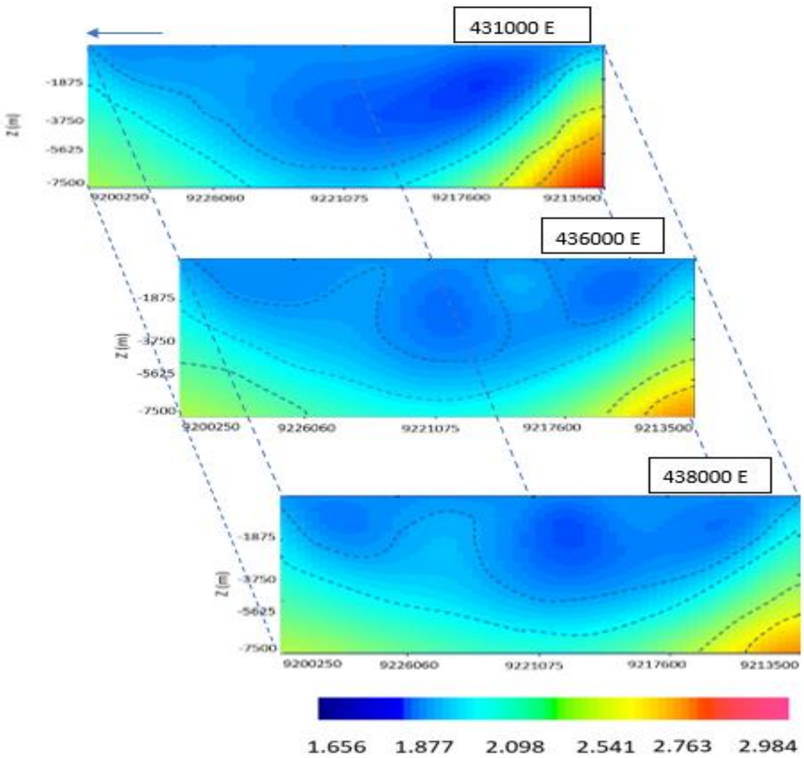

Figure 10. Cross-section on Easting 3D inversion result

The 3D model in the picture of the cross-section is located at coordinates X 431000 m, 436000 m, 438000 m (Figure 10). These cross-sections are across Kerek formation, Kalibeng formation, Kaligetas formation, Damar formation, and alluvium. The maximum density in this incision is shown in yellowish red to dark red with a density range of 2.85 g/cc to 3.00 g/cc located at coordinates Y 9213000 m to 9217000 m (south of the cross-section area), and 9227000 to 9229000 (next to north of the cross-section area), with depths ranging from > 2 km, the density value indicates that the area has rock types in the form of volcanic breccia, basalt, lava, and andesite. Referring to the density contrast value obtained from north to south of the rock formations in Table 3, these incisions are alluvial deposit formation, damar formation, and Kalibeng formation. The rock lithology is a volcanic breccia, basalt, volcanic, and andesite. These rocks are located at the base of the incision modeling and form a basement rock.

The others rock composition in this cross-section has a density range of 1.65 g/cc to 2.55 g/cc and indicates the presence of alluvium, clay, sandstone, and silt rocks located to the south and north of the incision. Clay rocks and sandstones are indicated in the southern area of the incision area with a depth of 4 km and are indicated by gradations of dark blue to light blue which has a density range of 2.0 g/cc to 2.5 g/cc, rocks in the northern area have a low density because the area is close to the coast and includes areas with alluvial sedimentary rock formations, there is a fairly contrasting density difference in the middle area of the cross-section area which indicates that there is a fault, the fault is also indicated east to west [21]. The clay and sandstone lithology indicated in this incision is located in the southern and northern areas of the incision with a depth of up to 5 km indicated by a dark blue to light blue color gradation with a density range of 2.0 g/cc to 2.3 g/cc, the fault indicated in this incision are thought to be a normal fault and the location is 9215000 m 9218000 m [17-21].

The application of the Chi Fact algorithm for gravity data inversion in the GRAV3D program produces a subsurface rock density distribution model. The same results as the results obtained by the algorithm used in the inversion process will greatly determine the computational time required. The optimal algorithm is highly dependent on the predefined data grid structure. The 3D inversion of gravity data can be done with a linear approach but this option can only be used for geological structures that are not estimated to be complex, or on localized structural geometries although it can also be used to determine complex density distributions such as at margins.

CONCLUSION

The Chi Fact algorithm in the gravity data inversion program can be used in the inversion of gravity data in the Kaligarang area of Semarang. The validation test that has been carried out using synthetic data shows that the Chi Fact algorithm can be used to determine the density distribution model in 3D. The results of the inversion of gravity data from a 3D model of the subsurface density of Semarang City with a density range of 1.64 g/cc to 2.98 g/cc shows the rock lithology in the form of volcanic breccia, basalt, volcanic, and andesite. The dominant geological structure in the Kaligarang area and its surroundings is a fault on the Stratigafi map of Semarang City. Identification of the presence of faults resulting from the inversion of gravity shows consistency with the presence of faults identified on the Stratigafi map of Semarang City.

ACKNOWLEDGMENTS

The authors gratefully acknowledge a member of Geodesy Laboratory – Diponegoro University, especially Mr. M. Laode Sabri, for their support of the fieldwork needed to acquire the data used in this study.

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