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Digital Elevation Model Construction Using Geostatistics and Geological Expert Knowledge – A Case Study in Oitti Area in Southern Finland

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Abstract. *Digital Elevation Models (DEMs) are an important topic in geographical information science as DEMs are commonly used in GIS analysis applications related to physical environment. There are various techniques used for modelling the elevation surface and in this study the focus is on interpolation methods based on geostatistical techniques. This study is further research extended from previous work in which the kriging method was applied in elevation modelling. In the previous research, it was shown that kriging is a suitable tool for constructing an elevation model in a study area which presented glacial and postglacial clays. Therefore, it was rather simple to build a DEM in that area by using the ordinary kriging method for interpolation. However, in many locations in Finland, it is not simple to build a DEM. The complex structure of the land formation may result in a complicated structure. Quaternary deposits consist of elongated moraine ridges that affect the geomorphology and, so, the elevation model. In Finland, the elevation model of moraine ridge areas is important because sources of fresh water are situated in these kinds of land formations. Mapping of the groundwater areas is necessary because of the EU directives. The aim of this research is to present a comparison of two kriging approaches in building elevation models. In the first one, elevation model is built by using the same variogram model in the whole study area. The second kriging approach uses geological expert knowledge in order to divide the study area into three sub-areas, a clay-dominated area in the west and east and a moraine ridge in the centre. It was shown that expert knowledge of Quaternary deposits can be applied in digital elevation modelling in order to produce a higher-quality result.*

Keywords. *DEM, Kriging interpolation, Variogram modelling, Geological expert knowledge*

1 Introduction

Digital elevation models (DEMs) have been used in various environmental applications in geographical information sciences. A DEM is said to be a presentation of the Earth's surface in numerical format (Dowman, 1999). DEMs are used in many applications, for instance: in land mapping, e.g. topographic maps, forestry maps, and wetland maps; in transportation applications, e.g. land transportation and air navigation; in underwater applications, e.g. seafloor morphology and underwater archaeology; in engineering applications, e.g. coastal engineering, water supply, and floodplain management; in commercial applications, e.g. real estate management, and in military applications, e.g. terrain and mobility analysis and in individual uses (Maune et al., 2001). A special need for accurate elevation models is the European Union´s water framework and nitrate directives according to which the groundwater areas must be identified, classified and reported (Europa, 2008).

The study is a continuation study from previous research into an elevation model using geostatistical approaches. In the previous study (Sunila and Kollo, 2007), elevation surfaces were interpolated using the kriging technique. Several kriging models were constructed in order to select the best-fit model for representing the interpolation of elevation data. The resulting map was presented in 2D and showed the smooth elevation surface of a study area. It can be concluded from the previous study that if the elevation data are sufficient, the interpolation can be viewed comprehensibly. However, only a sufficiency of data may not be adequate to create a clear view of the elevation surface presentation; the knowledge of the area can be added to the model to create a more reliable and comprehensible resulting model of the elevation data. This idea inspired the authors to take the research further with an extended approach in which information related to the study area is taken into account and expert knowledge of the area is included in the construction of the model. By expert knowledge in this context we mean knowledge on geology, especially on geologic structures obtained from field experience and outcrop studies (Corvi et al., 1992). This knowledge has been achieved by the geologist during his/her years of working in this field. Knowledge is quite often very difficult to encode to the model itself (Andrienko et al., 2008), thus using the expert knowledge in an interactive way together with the mathematical model solution seems an interesting solution. In our approach the expert user interprets the results of geostatistical analysis and then applies visual analysis of the quaternary deposits map and based on these results makes his/her decisions on further steps in the modelling process. The sufficiency of data points, together with geomorphological knowledge of the area, can influence the effectiveness of the model, which affects the quality of the resulting map as a final product. Beneficially, kriging is not only a very useful tool for mapping and estimating datasets and conducting smooth surface interpolation, but it can also be used to characterise uncertainty as the method is based on probability theories and concepts and so it can cope with estimating unknown reality data points.

In this research, the main focus is on how to implement and use geological knowledge, e.g. the knowledge of quaternary deposits, for modelling elevation data. The motivation of this study is to search for solutions which are generally applicable for Finnish conditions. A study area in Hausjärvi, southern Finland, and named Oitti was selected because in this area, Quaternary deposits have elongated structures, and the underlying bedrock has deep bedrock valleys. Both affect the overall elevation in the area. The aim of the paper is to discuss how kriging interpolation may be applied in building an elevation model in the area of complicated geological structures. This is an important topic because the Oitti area has a history of water and waste problems. In this study, the results from ordinary kriging were compared using a single variogram model for the whole study area, and variogram models specific for geologically homogeneous subareas using expert knowledge based on a map of the quaternary deposits. The different methods were compared quantitatively using the mean error (ME) and the root mean square error (RMSE). The methods were also compared according to their practical applicability.

2 Landforms and Quaternary Deposits of Finland

"Finland is a rather flat country" (Granö et al., 1986). The place named Halti is the highest point of Finland and is located in the northwest of Lapland on the Norwegian border, with a height of 1,328 metres above sea level (Granö et al., 1986). The high mountainous country areas with a height above 200 metres are mostly in the eastern part of Finland up to Northern Finland or Lapland. Western and southern Finland are mostly hillock and flat country, with a height between zero and twenty metres.

The quaternary deposits of Finland have been systematically mapped since the 1870s. In 1979, the Geological Survey of Finland and National Board of Survey agreed to collaborate on quaternary mapping and map updating in Finland. After the mapping schedule was approved, the continuous covering of areas in Finland by maps of quaternary deposits began. The resulting maps represent 2D models of deposits to a mapping depth of one metre, with different soil types depicted by soil polygons. There are four map types defined for different parts of the country on scales of 1:20,000 and 1:50,000 (Haavisto, 1983). The history of quaternary deposits in Finland is less than 12,000 years old. The quaternary deposit regions in Finland can be differentiated into two main regions, a southern zone of fluvioglacial deposits in which the main landforms are eskers and a northern zone of mainly streamlined till with drumlins (Sugden and John, 1976). During the deglaciation period, the glacier movement and erosion affected the land formation and deposits. Glacigenic depositional landforms exist throughout Finland. The movement of glaciers creates drumlins and rock drumlins. Moraine ridges are accumulated in the area along the margin of the ice sheets.

3 Material

The area named Oitti in Hausjärvi was chosen for this study. The study area is located in Southern Finland. The concentrated area of the study is about 25 square kilometres. The area has a history of glacial deformation and glaciofluvial relief. Drumlin fields are widespread in this area. The area was chosen as a case study because geological expertise revealed that there are cross-fractures of the landforms in the area in which the fractures across the moraine ridges are deeper than the fractures along the ridges (Laine, 1998; Niini, 1968). A quaternary deposit

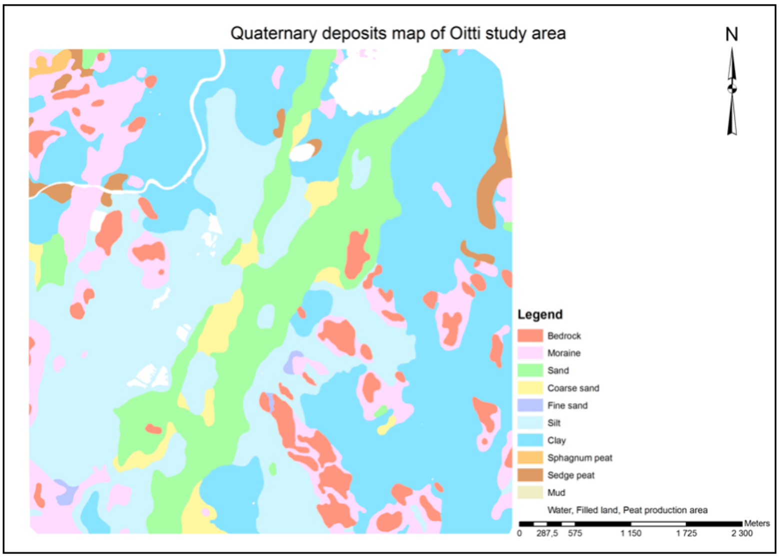

Figure 1. *Map of quaternary deposits of study area in Oitti. (Source: Geological Survey of Finland.)*

map of the study area is shown in Figure 1. It appears that the moraine ridge area, composed of sand on its surface, is elongated from the south-west to the north-east. In the south-eastern corner the bedrock outcrops in zones from the south-east to the north-west.

Oitti is one of the areas in Finland in which groundwater is a problem. Some groundwater wells have already been closed. The reasons in general for the groundwater problems are land extraction and plant protection chemicals as well as contamination from industry, petrol stations, landfills and use of salt for de-icing roads. Finnish Environmental Institute makes hydrogeological mappings in which the goal is to produce as accurate mapping of the groundwater areas as possible. Accurate elevation model is of core importance. The latest technology, laser-scanned elevation models might be one solution, but only in the future, they are not yet available throughout Finland. Oitti area has not been laser scanned and the most accurate DEM that can be built is the one based on the traditional elevation data, the contours made for the topographic mapping purposes at National Land Survey of Finland.

3.1 Elevation dataset

The elevation dataset of the study area from the National Land Survey of Finland is shown in Figure 2. These data were extracted from the contour lines of the topographic maps and interpolated to a grid. The production process of digital elevation data contains aerial photography performed by aeroplanes and visual observation. The scale of the aerial photos is about 1:30 000. The scale 1:16 000 is possible to used for specific cases. The aerial photos are scanned and the resulting ground pixel resolution is 60 centimetres. Aerial triangulation is performed and the stereo models are used for digital elevation model editing. Currently, a 25 metres grid digital elevation model is used in Finland. The maximum error in height is about 2 metres (Pätynen, 2002). The distance between contour lines is 2.5 metres. The histogram of the elevation data of the Oitti study area is presented in Figure 3 in order to view the distribution of the data set. The total number of elevation samples is 16,090 points, corresponding to a sampling density of about 640 points/km^2. The minimum height is 82.50 metres and the maximum is 140 metres. The mean height is 103.46 metres and the standard deviation is 11.70.

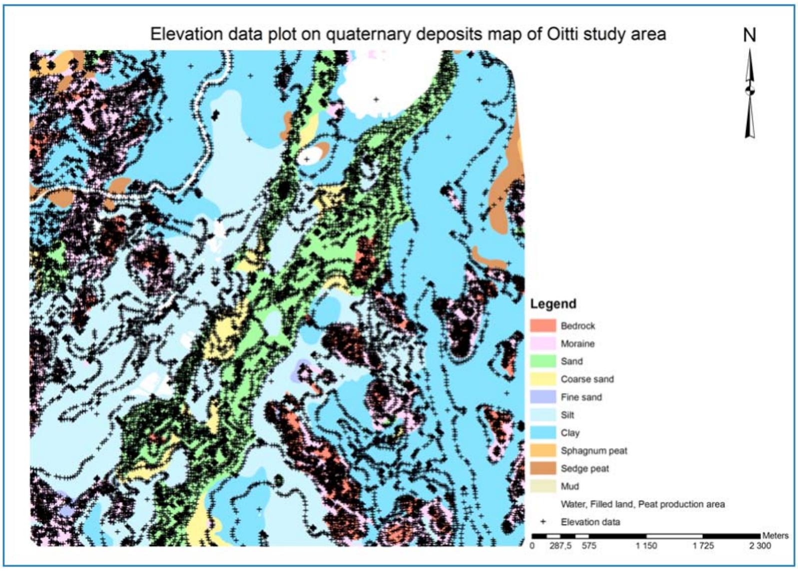

Figure 2. *Elevation data plot of map of quaternary deposits of study area in Oitti. (© Maanmittauslaitos 2009.)*

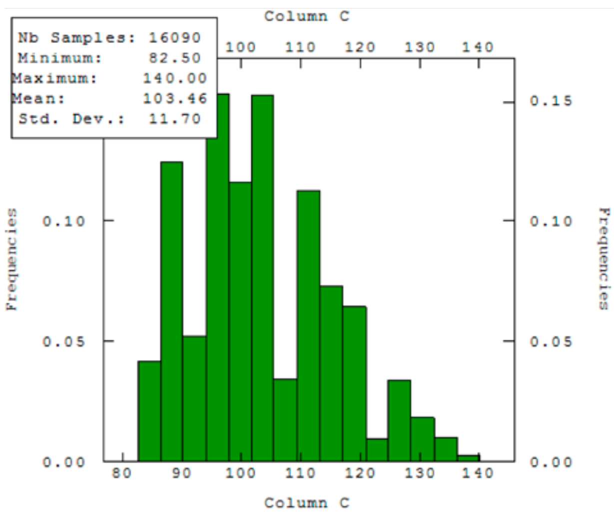

Figure 3. *Histogram of elevation data of Oitti study area.*

3.2 Data Analysis

The three most dominant soil types in the study area are concentrated on for statistical analysis (Table 1). The highest elevation values are within the sand area, where the moraine ridge is, and the bedrock outcrop area.

Table 1. *Statistical analysis of elevation data of three most dominant soil types.*

Soil Type	Samples	Min. (m)	Max. (m)	Mean (m)	Std. Dev. (m)
Bedrock	12,822	100.39	137.50	102.35	11.28
Clay	2,152	82.50	105.00	90.07	4.82
Sand (moraine ridge)	3,880	85	137.50	112.25	11.62

The evaluation of the elevation data in the sand and clay areas is the main focus in this study. From the map of the quaternary deposits of the study area, the sand is clearly presented in the middle of the area where the ridge is located. The clay area can then be assumed to be the area surrounding the ridge. The two areas are studied in depth using variogram maps. A variogram map is a representation of a variogram in all directions. The principle is to define a grid such that the origin of the space is located in the centre of this grid. Each pair of samples corresponds to a distance and a direction, which can be converted into a grid cell and to a variability, which contributes to the cell valuation. The variogram maps were calculated using a cell size of about 175 metres. According to the variogram maps (Figure 4), the central moraine ridge area differs from the surrounding areas by having a clear preferred orientation from the south-west to the north-east. The sand area shows that there is a direction in the model such that the variogram model for the moraine ridge area should be modelled with anisotropy and the clay area can be modelled with isotropy.

Thus, it is reasonable to divide the whole study area into three sub-areas, the western area (A), central area (B), and eastern area (C). This is also visible on the map (Figure 5) and the expert geologist can outline the different subareas based on both geostatistical and visual analysis and decision making.

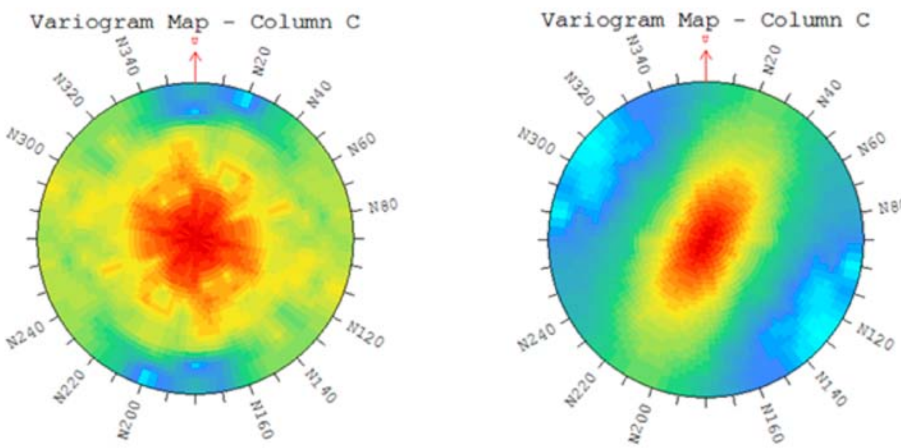

Figure 4. *Variogram map of elevation data in (left) clay and (right) sand areas.*

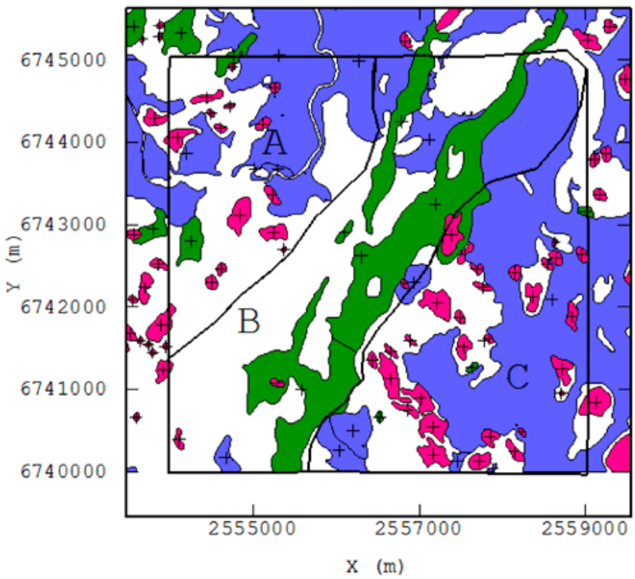

Figure 5. *Division of the study area into three different sub-areas, A, B, and C.*

Accordingly, the study area is divided into three areas (Figure 5):

– western area A, with surficial deposits without any clear orientation;
– central area B, containing a moraine ridge elongated in the south-western-north-eastern direction;
– eastern area C, with bedrock outcropping in zones in the south-eastern-north-western direction.

The histograms of the elevation data are plotted for viewing the density of data in each sub-area are presented in Figure 6 and the statistical summary of the three sub-areas is presented in tabular form in Table 2.

Table 2. *Statistical summary of elevations in three subareas.*

Area	**A**	**B**	**C**
Samples	4,642	6,052	5,391
Minimum	82.50 m	85 m	84.50 m
Maximum	130 m	137.50 m	140 m
Mean	101.55 m	108.06 m	99.94 m
Standard deviation	10.80 m	12.87 m	9.12 m

It is obvious that these areas have different spatial properties that also affect the elevation model. Figure 7 presents variogram maps of the elevation data from these different areas. The variogram map is a rasterised surface for which the value at distance $h = (h_1, h_2) \in R^2$ where h_1 is the distance in east-west direction and h_2 is the distance in north-south direction. The value at distance h gives the variogram value which is half the mean squared difference between the values Z at the two points separated by vector difference h. Accordingly, the central area differs, with a clear preferential direction along the moraine ridge. In the eastern

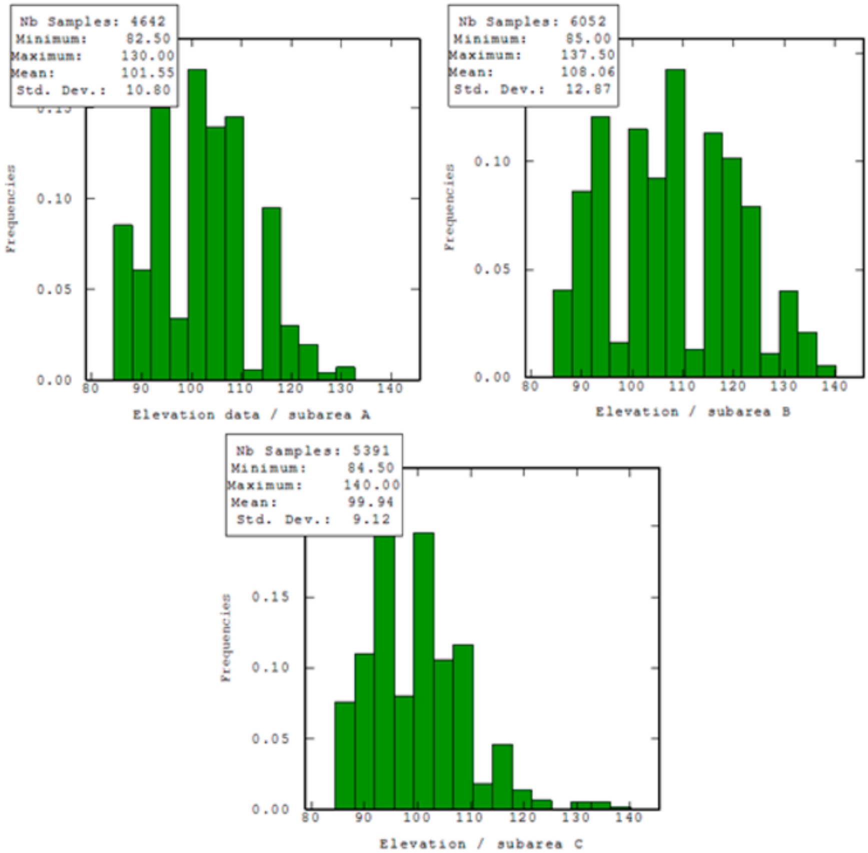

Figure 6. *Histogram of the elevation data of the study area in Oitti.*

area there is a preferential direction from the south-east to the north-west caused by bedrock outcrops – actually from large-scale bedrock fracturing in the area (Laine, 1998).

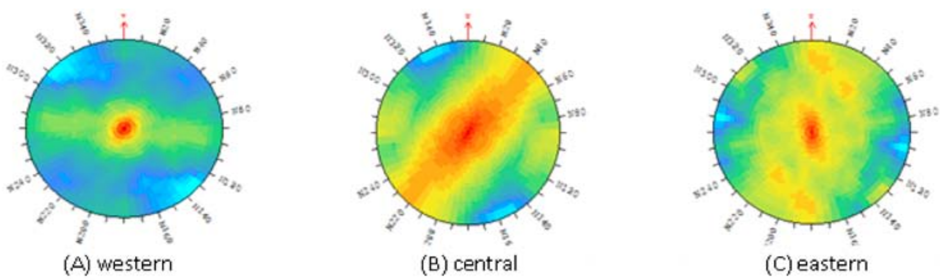

Figure 7. *Variogram maps for a lag of 174 m for the three different sub-areas: (A) western area, (b) central area and (C) eastern area.*

4 Kriging interpolation and validation

In this research, kriging (e.g. Matheron, 1963; Goovaerts, 1997; Chiles and Delfiner, 1999) is used for modelling the digital elevation data in the study area. In kriging the goal is to produce a continuous surface by using a discrete point data set an input. Kriging is a generic name adopted by geostatisticians for a family of generalized least-squares regression algorithms and named after Daniel G. Krige (Matheron, 1963). In this research, we focus on ordinary kriging applied to the original elevation data because it accounts for local fluctuations of the mean by limiting the domain of stationarity to the local neighbourhood containing the unknown value.

In ordinary kriging the mean is unknown and constant within the local neighbourhood. So the mean may vary in space but it should do so sufficiently slowly to be considered constant within the estimation neighbourhood.

The basic equation used in ordinary kriging is shown in Equation 1. (Note that the variables in the equation will be mentioned the first time and then they will be denoted throughout the text.)

$$\hat{Z}(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \tag{1}$$

where $\hat{Z}(x_0)$ = unknown values
n = number of data points in the search neighborhood
λ_i = weights of each sample point
$Z(x_i)$ = known values

The weights λ_i depend on the vector difference between x_0 and x_i in a way that is determined by the variogram. When the estimate is unbiased, the weights are made to sum to 1 or $\sum_{i=1}^{n} \lambda_i = 1$. The ordinary kriging variance is given by:

$$\sigma^2(x_0) = \sum_{i=1}^{n} \lambda_i \gamma(x_i, x_0) + \varphi \tag{2}$$

where σ^2 = ordinary kriging variance
$\gamma(x_i, x_0)$ = semivariance between sample point x_i and unknown point x_0
ϕ = Lagrange multiplier

Ordinary kriging relies on modelling the spatial correlation structure of the data to determine the weighting coefficients. Spatial correlation is modelled using the experimental semivariogram calculated by Equation 3.

$$\gamma(h) = \frac{1}{2N} \sum_{i=1}^{N} \left[Z(x_i + h) - Z(x_i) \right]^2 \tag{3}$$

where h = lag distance
N = number of sample pairs separated by h
$Z(x_i)$ = sample value at x_i.

The experimental variograms are modelled using simple mathematical models such as ‘spherical’ and ‘exponential’. The spherical model is described in

Equation 4.

$$\gamma(h) = \begin{cases} c_0 + c_1 \left\{ \dfrac{3h}{2a} - \dfrac{1}{2}\left(\dfrac{h}{a}\right)^3 \right\} & for\ 0 < h < a \\ c_0 + c_1 & for\ h \geq a \end{cases} \tag{4}$$

$$\gamma(0) = 0$$

where α = range
c_0 = nugget variance
$c_0 + c_1$ = sill

The exponential model is the second variogram model chosen in this study as it fits the behaviour of the data; the exponential variogram is presented in Equation 5.

$$\gamma(h) = c_0 + c_1 \left\{ 1 - \exp\left(-\frac{h}{a} \right) \right\} \tag{5}$$

Validation is a procedure that gives evidence that a study conforms to its declared objectives (Olea, 1991). The cross-validation method used in this study is the leave-one-out cross-validation technique. The leave-one-out cross-validation technique is performed in such a way that the data are tested N times and each time the algorithm trains with $N - 1$ of the subsets and tests with the remaining subset. The estimated height (Z*) is then was compared at each point to observed height (Z) using the mean error (ME) Equation 6.

$$ME = \frac{1}{N} \sum_{i=1}^{N} (Z^* - Z) \tag{6}$$

and the root mean square error (RMSE) Equation 7.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (Z^* - Z)^2}{N}} \tag{7}$$

ArcGIS (ESRI) and ISATIS (Geovariances) are used in this research. The map of the quaternary deposits and data plot of the study area were presented by means of ArcGIS. The variogram models and kriging interpolation were constructed using ISATIS.

5 Method

5.1 Variogram Modelling

The variogram modelling is a critical step in kriging interpolation. In this study, the variogram models are constructed on the basis of two different study models, a single model in which a whole study area is represented by one variogram model and a sub-area model in which each three areas has its own variogram models, so that three variogram models are presented in the sub-area model. The building of the variogram model can be said to be a tailor-made step as the knowledge of the study area and the experience of the researchers are the basis on which the judgment of how to select the type and set the variables for the particular variogram model is made.

5.1.1 A single model approach

In this case, the best results were obtained by calculating an isotropic variogram having an angular tolerance is 90° and a lag of 133.43 metres. The exponential model with a range of 1400 m and a sill of 144 was fitted to this experimental variogram (Figure 8 and Table 3).

***Table 3**. Variogram model for the whole study area.*

Structure	Model	Range	Sill
1	exponential	1,400 m	144

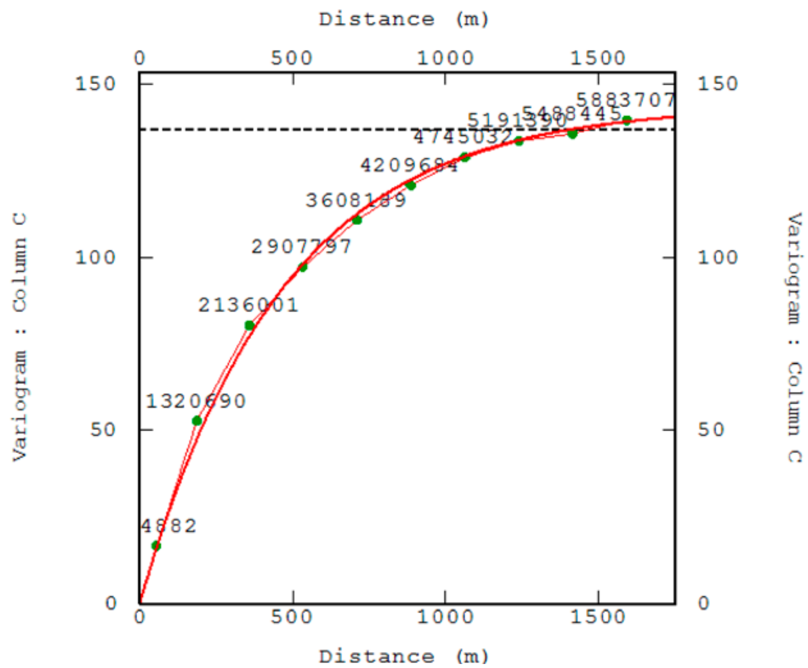

Figure 8. *Experimental variogram of the elevation values in the whole area and fitted variogram model.*

5.1.2 Sub-area approach

The geological knowledge, which, in this case, means the knowledge of the quaternary deposits, is added to the model in order to divide the study area into three sub-areas. Based on the variogram analysis for different soil types and visual analysis of the quaternary deposits map the geologist can outline the three subareas that can then be modelled separately. Figure 9 presents the concept of the modelling of the sub-areas.

In this study, a variogram model is constructed using one or more model functions or structures as a combination; it is also called a nested structure. The model variogram then represents the combination of all of the nested structures. It is noted that the nugget is the same for all the nested structures and it was assumed to zero. Although, in most cases, a single variogram model is adequate, in some cases multiple variogram model structures can be useful, especially in cases with a complex experimental variogram. Experimental variograms were calculated in eight directions, which are N 0°, N 23°, N 45°, N 68°, N 90°, N 113°, N 135°, and N 158°. The lag was 105.40 metres and the angular tolerance 22.50°.

The first sub-area is called the western area (area A). The number of elevation data points in this area is 4642. The second sub-area is named the central area (area B). The central area is the area where the ridge is located and the surrounding areas along the ridges are included. The number of sample points is this area is 6052. The third sub-area is named the eastern area (area C). The area lies on the right-hand side or to the east of the ridge and contains 5391 elevation sample points.

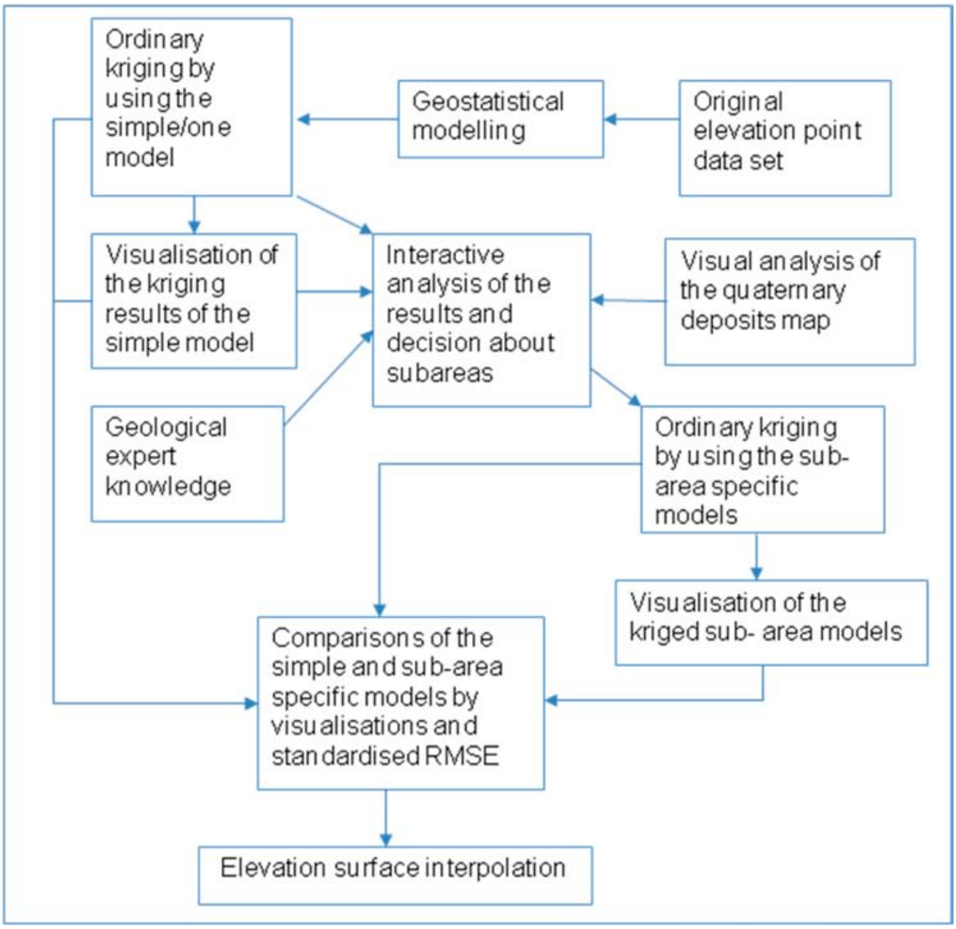

Figure 9. *Concept of the use of expert knowledge together with geostatistical modelling.*

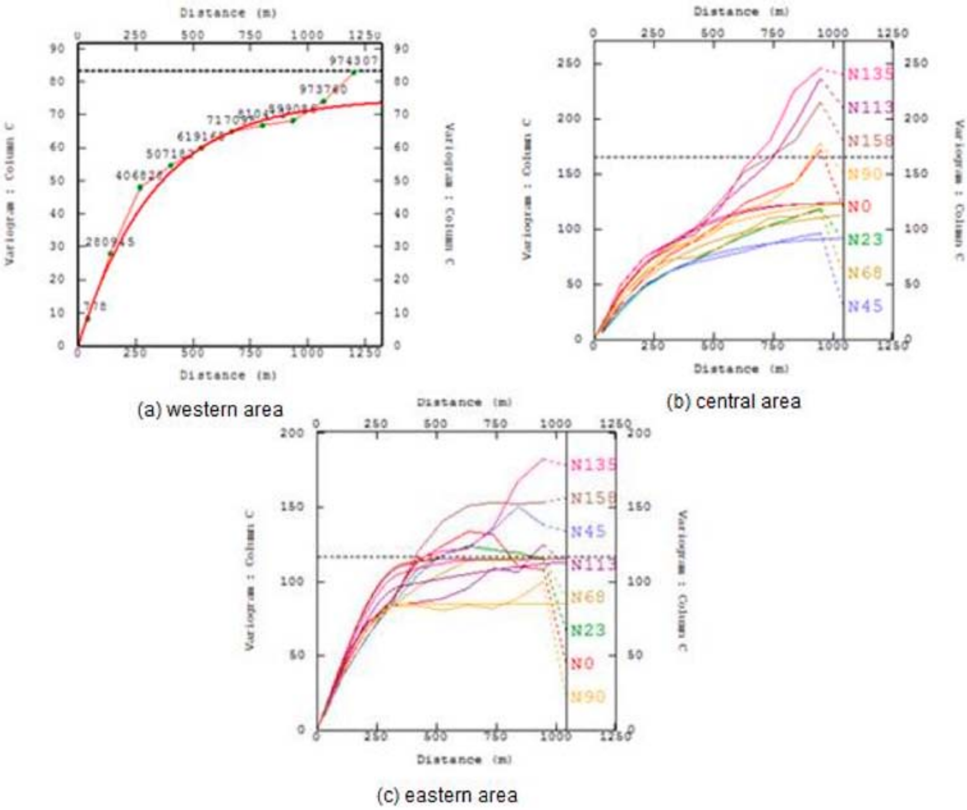

Figure 10. *Variogram models of the elevation data from the three sub-areas.*

The experimental variograms for the western area A were modelled using one isotropic spherical variogram model. The experimental variograms for the central area B were modelled using exponential models representing the direction of maximum continuity to the North and the higher variability of the elevation in the perpendicular direction. For the eastern area C, the exponential model has its direction of maximum continuity 45 degrees from the North and the spherical model is representing the higher variability across the direction of the moraine ridge.

A summary of all the variogram models used in the sub-areas is presented in Table 4. The variogram models for each sub-area are shown in Figure 10. The variogram models for elevations in the three subareas are quite different. The preferred orientation of the subarea A has no obvious geological explanation. In contrary the anisotropy direction found in the central subarea B is parallel with the moraine ridge orientation. The elevations in the eastern subarea C are affected in addition to Quaternary geology by bedrock structures perpendicular to moraine ridges in the area resulting too complicated anisotropies to be modelled using a single anisotropy model. The obtained variogram models are using in kriging two elevation models.

***Table 4**. The variogram models.*

Area	Structure	Model	Range	Sill
Western	1	spherical	1,000 m	75
Central	1	exponential	350 m.	85
	2	exponential	500 m (N), very large (E).	30
Eastern	1	exponential	900 m (NW), 700 m (SE).	95
	2	spherical	Very large (NW), 800 m (SE).	30

6 Results

6.1 DEM interpolation map of single model

The kriged elevation map using the same isotropic variogram model in the whole study area is shown in Figure 11. The applied variogram model was tested using cross validation. The mean standardised error (ME) is 0.0054 metres and the root mean square standardised error (RMSE) is 0.3277 metres.

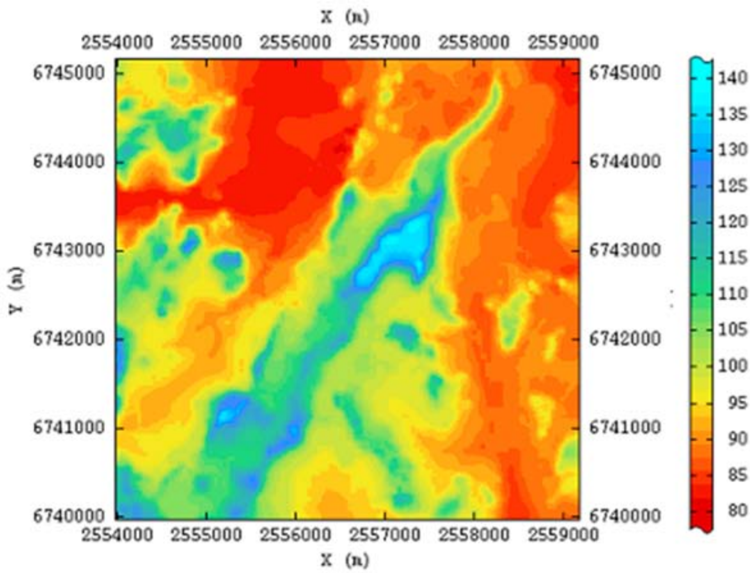

***Figure 11**. Elevation map resulting from ordinary kriging.*

6.2 DEM interpolation map of model applying expert knowledge

When the three sub-area models are combined together, an interpolation of the whole study area is drawn. The kriged map obtained by using specific variogram models in each of the three subareas is shown in Figure 12, and presents the elevation surface interpolation of the study area as a whole. The three polygons represent the boundaries of the three sub-areas, the western, central, and eastern areas. The resulted map looks very much the same as the one resulted by using one single variogram model for the whole area.

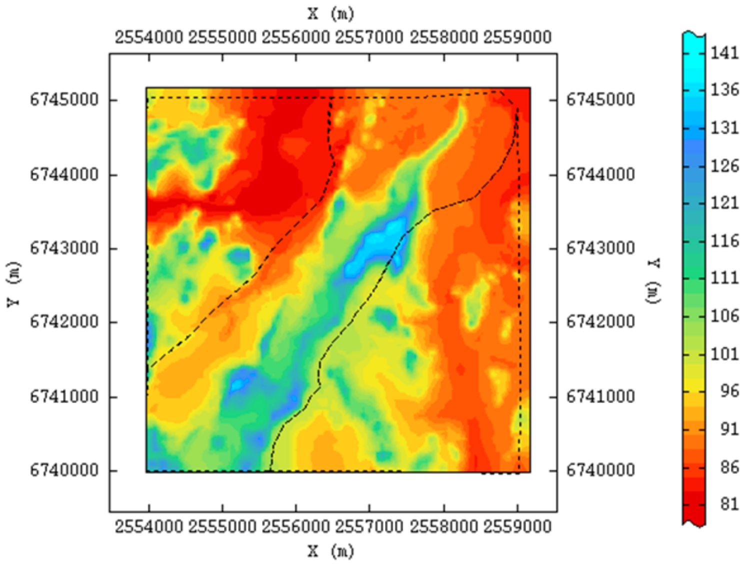

Figure 12. *Elevation map resulting from ordinary kriging applying expert knowledge approach.*

The cross validation gives the following results for the variogram models specific for subareas (the unit is metre):

- Western subarea (A): ME = 0.0080 and RMSE = 0.2238,
- Central subarea (B): ME = 0.0072 and RMSE = 0.2980, and
- Eastern subarea (C): ME = 0.0138 and RMSE = 0.3480.

6.3 Comparison of the two models

To compare the results between two approaches, the standardized mean error ME and the root mean square RMSE outcomes were used. The comparison of cross validation resulted from the two approaches are presented in table 5. To compare the results between two models, the mean value of RMSE outcomes from the second model in which geological expert knowledge were applied was calculated. The mean of standardised RMSE of the second model is 0.2934 where the standardised RMSE calculated from the first model is 0.3277. The mean of standardized of the second model was calculated base on the number of observations in each subarea. It can be concluded that the variogram model with expert knowledge in which the area is divided into subareas yielded better result than the single variogram model.

Table 5. *The comparison between the standard deviation of the two models.*

Standardised RMSE – Ordinary kriging using single model (metre)	**Standardised RMSE – Ordinary kriging using a variogram model specific to the sub-areas (metre)**
	sub-area (A) 0.2238
0.3277	sub-area (B) 0.2980
	sub-area (C) 0.3480
	mean 0.2934

The F-test is used to test if the model 2, sub-areas model, is more precise than the model 1, whole are model. Model 1 is more precise if its standard deviation is lower than that of the model 2. So, the null hypothesis $H_0 : \sigma_1^2 = \sigma_2^2$ against the alternate hypothesis $H_A : \sigma_1^2 > \sigma_2^2$. Table 6 presents the statistical test performed by F-test.

Table 6. *Statistical performance using F test.*

Model 1: whole area	Model 2: Sub-areas
Number of observations = 16090	Number of observations = 16090
Standard deviation = 0.3277	Standard deviation = 0.2934
Standard deviation (Numerator) = 0.3277	
Standard deviation (Denominator) = 0.2934	
F-test value = 1.2475	
Degree of freedom = 16089	

Form the F-distribution table, with 95% confidence interval, $F_{16089,16089}$ = 1.0000. In this case the $F_{calculation} > F_{16089,16089}$, so the alternate hypothesis is accepted. It is interpreted that the sub-areas model yield more precise result than the whole area model.

7 Conclusion and Discussion

The study aims to show that elevation surface interpolation using a kriging interpolation can present a more realistic and reliable resulting map presentation by including expert knowledge into the model. The study compares the maps obtained from two different approaches, the one using one variogram model for the whole area and subarea specific variogram model approach using subarea specific models in kriging interpolation. The subarea specific approach used expert knowledge to classify the study area into three sub-areas. The resulting maps presented relatively satisfactory visual representations of the elevation information in the study area. The map resulting from a single variogram approach represents the elevation surface roughly. The map using specific variogram models for the sub-areas presents the height information of the study area in more detail. However, when the two maps resulting from the use of the two approaches are compared, the results from both models are acceptable for spatial analysis.

Although the map resulting from the single variogram model approach represents an acceptable interpolation, the map resulting from the subarea specific variogram model approach yields a more reliable and more precise interpolation of the study area. The differences between the two maps are, as mentioned earlier, that maps resulting from subarea specific variogram model approach yield a more detailed interpolation of the elevation surface. Therefore, they are suitable for spatial analysis which requires very high accuracy and quality on the part of the interpolated maps. Obviously, to create a subarea specific variogram models that indicates more precise height information on the map and gives a more realistic visual representation of the elevation surface map, more effort is required. The subarea specific variogram model approach is time-consuming, as it requires more computational time and more effort in designing the model. The additional expert knowledge plays a key role in constructing a sub-area model. To obtain the expert knowledge on a concentrated area, more resources are sometimes an obstacle as they often relate to costs and time. It is difficult to decide or judge the level of the knowledge to be used or included in the construction of the model. For an application in which imprecision in the surface interpolation is acceptable and realised, a single variogram model approach can provide an alternative to a quick and less complicated method for presenting the elevation of the surface and the resulting map is usable. Otherwise, a subarea specific variogram model approach gives another alternative for those applications in which a surface presentation with a high level of precision is required. It should also be mentioned that when doing this research also more complicated kriging models were considered, however the use of them was not possible in this study due to the data set being large and computational capacity limited. From the user point of view it is good if a relatively simple mathematical model can be used, so that the user has some possibility to understand the logic. The use of ordinary kriging and expert knowledge together gives a method that is understandable for the user and computationally acceptable.

When the use of the general model is compared to the use of specific models it appears that the subarea specific variogram model gives better kriging interpolation results in the central moraine ridge and western clay-dominated area. However, there is no improvement in the area where the bedrock outcrops, showing an orientation parallel to the bedrock fracturing. This, together with the moraine ridge structures, creates landforms that are difficult to model using simple mathematical models such as variograms. The most important result is that the anisotropic variogram model within the moraine ridge area improves the kriging interpolation. This is important in the estimation of water resources.

In addition to elevation, the use of the geological expert knowledge could be used, for example, in the kriging interpolation of porosity for water resource estimation and mapping ground water pollution. In this case, the soil type is important, e.g. the porosity of sand is much higher than the porosity of clay and crystalline rock.

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