REPUBLIC OF TURKEY
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LARGE SCALE LANDFORM MAPPING USING LIDAR DEM

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MSc. THESIS
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A thesis submitted by Moustafa Khalil M. BAKER in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 09.02.2015 in Department of Geomatic Engineering, Geomatics Engineering Program.

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Moustafa Khalil M. BAKER

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LIST OF SYMBOLS

r	Radius of the neiborhood
pi	3,141592653589793238

LIST OF ABBREVIATIONS

DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
LIDAR	Light Detection And Ranging
SOTER	Global Soil and Terrain Database

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ABSTRACT

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Landform is often the most important factor in distinguishing between regions and an important element of geographic classification, typification, and regionalization. One of the best-known classifications was developed by the American geographer Edwin H. Hammond (1954), who classified the landforms of the United States in great detail. It has since been modified into a deterministic analysis which can be computed using elevation data and performed in a GIS. More recently, Morgan and Lesh (2005) has developed pixel-based analysis approach using GIS. All of these approaches have been used to obtain landform maps at medium or small scales using coarse resolution DEM such as USGS NED, ASTER GDEM and SRTM so far .

In this study, using LIDAR DEM data, a landform map was firstly obtained in accordance with Morgan and Lesh's workflow. In this stage, radius of the search window in neighborhood operator was determined as 50 pixel by trial and error. Futhermore, an interface was developed so that some of the parameters in the model could be changed by the user besides the automation of Morgan and Lesh's workflow. In order to make the slope threshold a model parameter in the interface a logical tool (Greater Than) was used instead of slope reclassification tool in Morgan and Lesh's model. Lastly, this landform map was generalized using focal statistics (Majority) considering minimum area condition in cartographic generalization in order to obtain landform maps at 1:1,000 and 1:5,000 scales.

Both the primary and the generalized landform maps were verified with hillshaded DEM and orthophoto visually. As a result, all these maps show the landforms satisfactorily. Moreover, in order to show the effect of generalization, area of each landform in both the primary and the generalized maps was computed. Consequently, landform maps at large scales could be obtained with the proposed method including generalization using LIDAR DEM.

Key words: Landform classification, GIS, LIDAR DEM, Cartography ,Generalization, Minimum area.

ÖZET

LIDAR SYM VERİLERİNDEN BÜYÜK ÖLÇEKLİ ARAZİ ŞEKLİ HARİTALARININ ÜRETİMİ

Moustafa Khalil M. BAKER

Harita Mühendisliği Anabilim Dalı

Yüksek Lisans Tezi

Tez Danışmanı: Doç. Dr. Türkay GÖKGÖZ

Arazinin şekli, bölgeleri birbirinden ayırt etmede kullanılabilecek en önmeli faktördür ve coğrafi sınıflandırma, tipikleştirme ve bölgeselleştirmenin en önmeli öğesidir. İyi bilinen ve yaygın olarak kullanılan arazı şekli sınıflandırmalarından biri Amerikan coğrafyacısı Edwin H. Hammond (1954) tarafından geliştirilmiştir. Hammond, Amerika Birleşik Develetleri için arazi şekillerini çok ayrıntılı olarak sınıflandırmıştır. Hammond tarafından geliştirilen yaklaşım, Coğrafı Bilgi Sistemleri ortamında Sayısal Yükseklik Modeli (SYM) kullanarak uygulanabilmesi için çeşitli bilim insanları tarafından geliştirilmiştir. John M. Morgan ve Ashley M. Lesh (2005) tarafından geliştirilen en güncel yaklaşımda CBS araçları kullanılarak piksel-bazlı analizler yapılmaktadır. Bu yaklaşımlar bugüne kadar yalnız orta ve küçük ölçekli arazi şekli haritalarının USGS (NED), ASTER GDEM ve SRTM gibi düşük çözünürlüklü sayısal yükseklik modellerinden elde edilmesinde uygulanmıştır.

Bu çalışmada, öncelikle LIDAR SYM verisi kullanılarak Morgan ve Lesh tarafından geliştirlen metodolojye göre bir arazi şekli haritası elde edilmiştir. Bu aşamada komşuluk öperatöründeki araştıma penceresinin yarıçapı deneme yanılma yolu ile 50 piksel olarak belirlenmiştir. Ayrıca, hem Morgan ve Lesh tarafından geliştirilen metodolojinin otomatize edilmesi hem de modeldeki bazı parameterlerin kullancı tarafından değiştirilebilmesi için bir arayüz geliştirilmiştir. Eğim eşik değirinin arayüzde bir model parametresi olaması için Morgan ve Lesh'in modelindeki eğim yeniden sınıflandırma aracı yerine bir mantıksal araç (...den Büyük) kullanılmıştır. Son olarak, bu arazi şekli haritası, 1:1,000 ve 1:5,000 ölçekli arazi şekli haritlarını elde etmek için kartografik genelleştirmedeki minimum alan koşlu göz önüne alınarak ve odaksal statistik (Çoğunluk) kullanılarak genelleştirilmiştir.

Hem birincil hemde genelleştirilmiş arazi şekli haritaları gölgelendirilmiş SYM ve ortofoto kullanılarak görsel olarak incelenmiştir. Kısaca, tüm haritalar arazi şekillerini beklenen ölçüde gösterilmektedir. Ayrıca, genelleştirmenin etkisini göstermek için hem birincil hem de genelleştirilmiş haritalardaki her bir arazi şeklinin alanı hesaplanmıştır. Sonuç olarak, büyük ölçekli arazi şekli haritaları LIDAR SYM kullanılarak önerilen metodolojye göre genelleştirme yoluyla elde edilebilir.

Anahtar Kelimeler: Arazi şekillerinin sınıflandırması, CBS, LIDAR SYM, Kartografya, Genelleştirme, Minimum alan.

CHAPTER 1

INTRODUCTION

1.1 Literature Review

Edward H. Hammond (1954, 1964) developed a macro landform classification procedure to identify landform types for the United States that has been used for mapping landforms around the world. Hammond’s classification is quantitative in nature with explicit definitions that can easily be applied by other researchers. Hammond’s procedure combines three important parameters—slope, relief, and profile type—to identify different landform, or terrain types. According to Hammond:

Landform (terrain type) = Slope + Relief + Profile

The combination of these attributes could provide as many as 96 landform units. Hammond determined that less than one-half of these are common in the United States, so he used only 45 units on his map. Hammond merged areas smaller than 2,072km2 into adjacent units so that he could generalize the information at the 1:5,000,000 scale of his published map.

These landforms (terrain types) were subsequently grouped by Hammond into broader landform categories, such as nearly flat plains, rolling and irregular plains, plains with widely-spaced hills or mountains, partially dissected tablelands, hills, low mountains, and high mountains [1],[2].

Dikau et al. (1991, 1995) attempted to apply Hammond’s procedure in their landform classification of New Mexico using Geographic Information Systems (GISs) which automates Hammond’s manual procedures. Their main modifications are that they used no generalization procedures and included all 96 landform units in their analysis. They changed some of the unit terminology used by Hammond, and modified window movement, and established their own groupings of broader landform categories [3],[4].

A new process developed by Brabyn (1998) that partly solves the problems with Dikau's et al. classification process and has been applied to the whole of New Zealand producing a classification that shows the macro landforms [5].

Morgan and Lesh (2005) implemented Hammond's model using the U.S. Geological Survey's 7.5 minute, 30-meter resolution National Elevation Dataset with ArcGIS ModelBuilder and generated Dikau's versions of Hammond's landform maps [6].

Gallant et al. (2005) automated a method for mapping Hammond's landforms over large landscapes using digital elevation data and compared their results against Hammond's published landform maps that derived using manual interpretation procedures [7].

Hrvatin and Perko (2009) tested the suitability of Hammond's method for determining landform units in Slovenia. First, they took the original classification elements into account and only thirteen units of the twenty-one landform units specified by Hammond were selected. They suitably adapted Hammond's original method due to the weaknesses were revealed the form and size of the basic window and the boundaries between classification element classes were changed. Nineteen landform units were thus identified in Slovenia using the adapted method [8].

Merina et al. (2011) obtained an automatic landform classification of Alicante province (Spain) at 1:25,000 scale, and properly methodology to do this delimitation because it has been contracted with the real landform by pictures [9].

Williams et al. (2012) directly compared of the Morgan and Lesh landform classes for areas shown in video views, against the most common participant landform terms given for the same location [10].

1.2 Objective of the Thesis

The main objective of this thesis is to obtain landform maps at 1:1,000 and 1:5,000 scales by using GISs and LIDAR DEMs that represents only base surface elevation data.

1.3 Hypothesis

LIDAR DEM data could be used for obtaining landform maps at large scales due to its high resolution.

Since LIDAR DEM data produces very detailed landforms generalization process is necessary for specified scales.

Generalization process could be managed by amalgamating of smaller areas recursively.

Minimum sizes in cartography could be used as a threshold in amalgamation process.

There is no fixed search window size which is valid for all application in any size of area with any DEM resolution.

Search window size must be determined for each study depending on the covering area and DEM resolution.

CHAPTER 2

GEOMORPHOLOGY, LANDFORMS and GEOMORPHOMETRY

2.1 Basic principles

The term geometry means literally ‘land (surface) measurement’, but has been applied mostly to artificial or smooth mathematical surfaces, such as spheres or cubes. Geomorphometry returns to the original meaning of geometry as a science devoted directly to quantitative analysis of the Earth’s surface. Geomorphometry has previously been considered as a sub-discipline of geomorphology but is now often regarded as a separate discipline in its own right. Most classifications of landforms are based either implicitly or explicitly on consideration of how the gravitational field interacts with the land surface with gravity governing surface flow and flow in turn modifying surface forms [11].

Specific geomorphometry applies to and describes discrete landforms such as an esker, drumlin, sand dune or volcano. It can involve arbitrary decisions and subjectivity in the quantification of its concepts. General geomorphometry applies to and describes the continuous land surface. It provides a basis for the quantitative comparison of even qualitatively different landscapes and it can adapt methods of surface analysis used outside geomorphology. Landforms were described mainly in two different ways (i) based solely on their geometry or (ii) based on semantics used to express and capture subjective conceptual mental models [11].

2.2 Landforms: Definitions

A landform is defined as “any physical feature of the Earth’s surface having a characteristic, recognisable shape”. A subjective semantic definition of landform consistent with specific geomorphometry is “a terrain unit created by natural processes in such a way that it may be recognised and described in terms of typical attributes where ever it may occur". Many geomorphologists, however, prefer a definition that includes recognition of artificial landforms such as quarries, waste heaps and similar. A geometrical definition of landforms, consistent with general geomorphometry, would focus on objective consideration of surface shape or form only. Landform types have also been referred to as relief forms, mesoform associations and landform patterns. Examples of landform types include plains, hills, mountains and valleys (Figure 2.1). Plains, hills and valleys can be observed at multiple scales. In geography, these names are used for larger landscapes dominated by one landform type. A landform element is a sub-component of a landform type at the level immediately below, and hierarchical to landform type. Landform elements may be conceptualised as consisting of portions of a landform type that are relatively homogeneous with respect to shape (profile and plan curvature), steepness (gradient), orientation or exposure (aspect or solar radiation), moisture regime and relative landform position (e.g. upper, mid or lower). Dikau (1989) differentiates form elements with homogeneous plan and profile curvature from even more homogeneous form facets that have homogeneous gradient, aspect and curvature. Shary (1995) and Shary et al. (2005) proposed an objective, local, scale-specific classification of elemental landform features based entirely on consideration of signs of curvatures. This classification was described as "predictable" in the sense that the proportion of an area occupied by each class can be calculated in advance for any terrain. It can be argued that any landform element that can be further sub-divided into smaller and more homogeneous entities is not technically an elemental form but the concept of a landform element has achieved widespread use in spite of this contradiction [11].

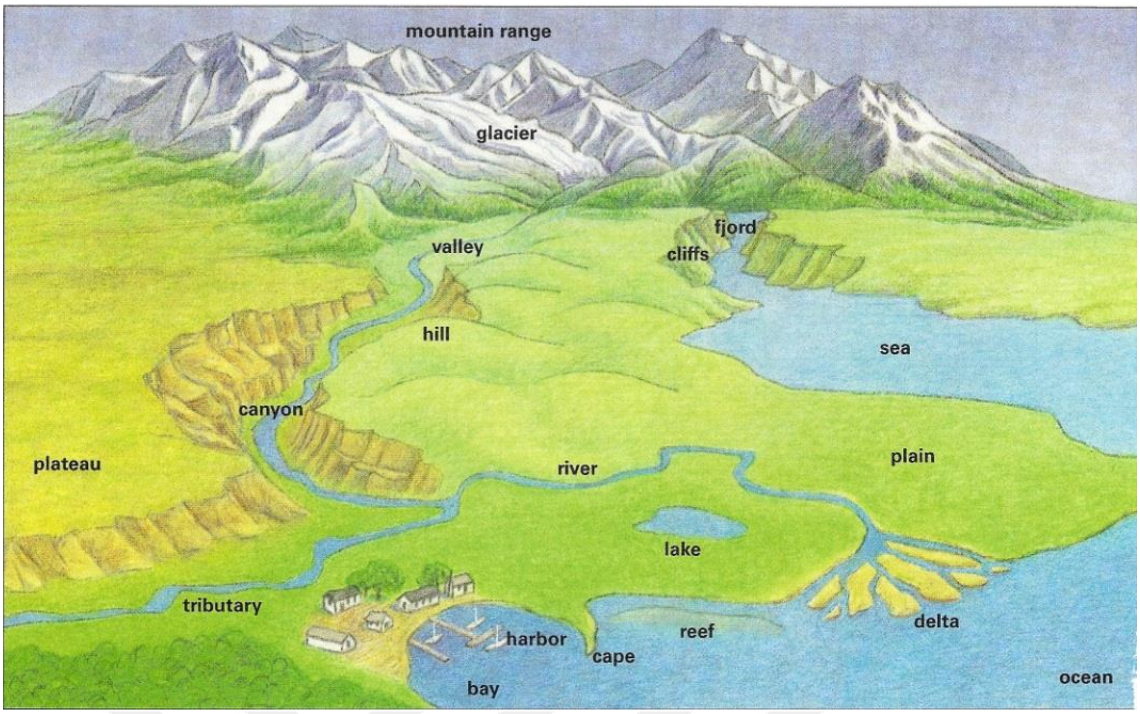

Figure 2.1 Examples of landform types [12]

2.3 Approaches to Landform Element Classification

Automated classification of landforms almost always represents an attempt to replicate some previously conceived system of manual landform classification and mapping. We briefly consider here some general aspects of manual approaches to landform classification that are relevant to efforts to develop and apply automated approaches. The system of Gauss (1828) recognised four field-invariant geometrical forms defined by signs of total Gaussian and mean curvatures (Figure 2.2). The system of Troeh (1964, 1965) partitioned land surfaces into four gravity-specific classes intended to recognise the two relative accumulation mechanisms based also on consideration of signs of tangential and profile curvatures (Figure 2.3) [11].

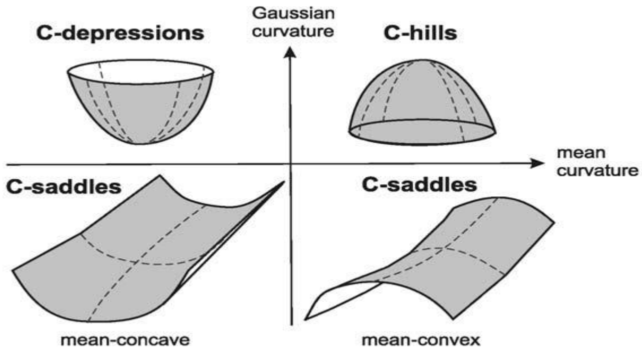

Figure 2.2 Illustration of the four landform classes defined by Gauss (1828) based on total Gaussian and mean curvature [11]

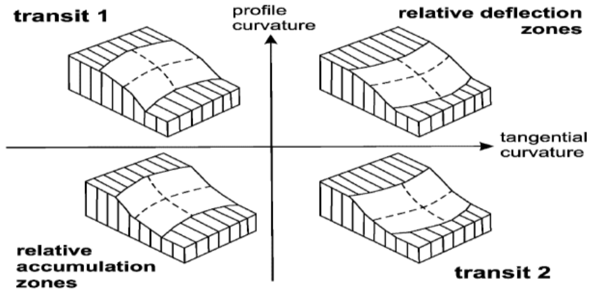

Figure 2.3 Illustration of the four landform classes defined by Troeh (1964, 1965) based ontangential and profile curvatures [11]

These systems can be applied to any surface at any scale to produce similar results.

Many subjective manual systems of landform classification have been proposed and extensively applied. Examples of widely applied systems include those of Fenneman (1938), Veatch (1935), Hammond (1954, 1964) for the USA, the Australian classification system of Speight (1974), Speight (1990), the SOTER1 (van Engelen and Ting-tiang, 1995), the ITC system of geomorphic mapping (Meijerink, 1988) and the geo-pedological approach by Zink (Hengl and Rossiter, 2003). Review of such systems is not possible within the constraints of this chapter however a few general observations are relevant. Manual systems of geomorphic classification are invariably hierarchical and implement a sub-division of land surfaces into successively more narrowly described (and typically homogeneous) forms at successively finer scales [11].

Manual hierarchical systems tend to implement the hierarchies using top– down, divisive approaches in preference to bottom–up agglomerative approaches. Most

[1] http://www.fao.org/ag/aGL/agll/soter.stm.

manual systems invoke semantic models that attempt to capture concepts deemed important by the classifier using subjectively formulated differentiating criteria. Manual classification systems tend be synoptic and synthetic and to require simultaneous consideration and synthesis of multiple differentiating criteria, with different criteria used to differentiate entities at different scales and even under different conditions at the same scale.

Primary considerations in differentiating landforms at different scales are local surface form or shape, landform size in horizontal and vertical dimensions, local to regional context, patterns of cyclic repetition of landform shapes as exhibited by topographic grain, topological relationships such as adjacency, connectivity and relative position, and hydrological relationships such as absolute or relative horizontal or vertical distance to channels, divides or water tables or position in the hydrological network relative to stream channel order. Classifications based on local land-surface parameters (such as curvatures) can be considered to be predictable, while most landform classifications based on regional land-surface parameters and objects should be considered as terrainspecific. A predictable classification does not mean that landform patterns can be predicted, but rather that the probability of occurrence of a given landform type can be calculated in advance. For example, Gauss' saddles (mean-concave and mean-convex, Figure 2.2) cumulatively occupy 2/3 of any terrain, as do Troeh's relative accumulation and deflection zones [11].

Argialas and Miliaresis (1997) identified a need to incorporate considerations of spatial reasoning into representation of landform classification knowledge in recognition that rules based solely on consideration of a landform's inherent pattern elements were incomplete. Spatial reasoning was captured mainly in terms of defining the context of individual landform elements. Argialas and Miliaresis (1997) and Leighty (2001) recognised that expert analysts make use of a priori physiographic information to focus their search for the correct identification of the landform at a site. An expert takes into account the regional context, the physiographic context, the geomorphic process context and other forms of context to arrive at an interpretation of a landform. In most manual systems of landform classification an expert who has familiarity with theoretical concepts applicable for differentiating landforms generally, and who may also possess specific familiarity with local landform types and arrangements, interprets available information about the land surface to partition it into spatial entities that separate and describe different landform classes. This is most commonly accomplished through manual visual examination of stereo air photos to interpret and delineate different patterns that can be observed in three dimensions on the stereo photos [11].

Several significant early examples of landform classification used topographic contour maps as the primary consideration for identifying and delineating landform entities (Hammond, 1954, 1964). More recently, landforms have been delineated manually on-screen against 2D and 3D backdrops that use various combinations of derivatives of digital elevation models (DEMs) or digital imagery, or both, to support this identification and delineation of landform entities.

Both manual and automated approaches to landform classification have tended to target recognition of classes that develop at one or more specific levels in multilevel hierarchies of landform entities. Speight (1974, 1990) proposed a two level descriptive procedure for a systematic, parametric description of landforms into landform patterns and landform elements. Following the work of Kugler (1964), Dikau (1989) conceptualised a similar hierarchy of entities of increasing size and morphological complexity referred to as form facets, form elements, relief forms and relief associations or patterns. The USDA Geomorphic Classification System recognises two hierarchical components termed landform and element landform [11].

Zinck and Valenzuela (1990) proposed four levels of landscape, relief, lithology and landform. The SOTER Global Soil and Terrain Database recognised a nested hierarchy of mapping units distinguished principally on the basis of physiographic criteria. Three hierarchical classes of entities of terrain, terrain component and soil component were identified. Most efforts to automatically classify landforms have targeted their classification efforts at entities that are approximately equivalent to one, and only occasionally both, of the two main hierarchical levels of landform patterns or landform facets (Figure 2.4) [11].

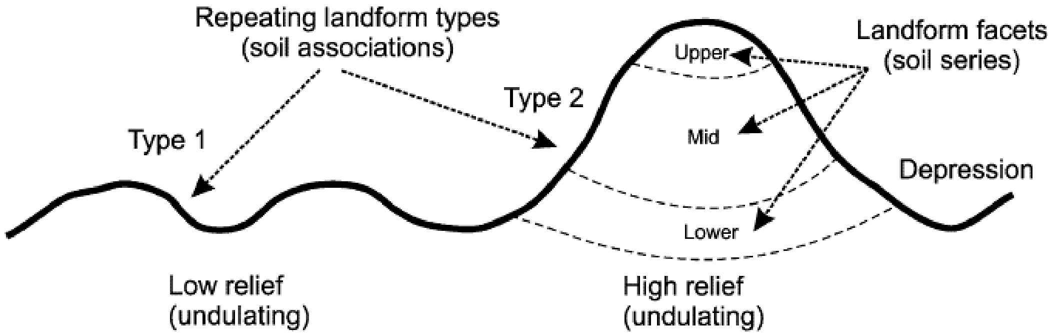

Figure 2.4 Illustration of conceptual differences between repeating landform types and landform facets [11]

CHAPTER 3

HAMMOND'S LANDFORM CLASSIFICATION METHOD

3.1 Description of Hammond's Method

In his detailed landform classification of the United States, Hammond used a square window of 6×6 miles (approx. 9.65×9.65 km) and an area of 93.12km^2 as the basic unit; this may seem large, but in terms of the United States this accounts for only 0.00001 of its territory. The windows followed one another with no overlap. On a 1: 250,000 scale topographic map, he identified three elements in each window: slope, local relief, and profile type. He marked every element with a specific sign and defined landform unit through their combinations.

The first element of Hammond's classification is slope. For each window, he calculated what percentage of its area had a slope less than eight percent (or approx. 4.57°). He marked this element with a capital letter:

A: > 80% gently sloping terrain,

B: 50–80% gently sloping terrain,

C: 20–50% gently sloping terrain,

D: < 20% gently sloping terrain.

The second element of Hammond's classification is local relief. He calculated the difference between the maximum and minimum elevation for each window. He marked this element with numbers:

1: 0–30 m,

2: 30–90 m,

3: 90–150 m,

4: 150–300 m,

5: 300–900 m,

6: 900–1,500 m.

The third element of Hammond's classification is profile type. For each window, he calculated what percentage of gently sloping terrain lay below or above the window's average elevation. He marked this element with a lower-case letter:

a: > 75% of gently sloping terrain lying in lowland areas,

b: 50–75% of gently sloping terrain lying in lowland areas,

c: 50–75% of gently sloping terrain lying in upland areas,

d: > 75% of gently sloping terrain lying in upland areas.

By combining these elements, Hammond identified landform units and put them on a large 1: 5,000,000 scale color map. However, he did not present the classification results in the form of squares, but through boundaries between the landform units that he defined subjectively by following the edges of plains, plateaus, low mountains, and similar large relief forms. Because of this, the map is somewhat generalized, but considerably less cluttered [1], [8].

3.2 Types of Hammond's Landform Units

Hammond thus used three elements with four, six, and four classes, respectively, to define landform units; theoretically, this represents 96 combinations or 96 possible landform units. However, he only selected twenty-one units (i.e., a good fifth of all possible combination), which he grouped into five landform groups.

To simplify this, Hammond defined the units according to the elevation of hills or mountains, and the percentage and concavity (or convexity) of the terrain above which they rise [1], [8].

The first group includes plains with the following four landform units:

Flat plains: at least eighty percent of the terrain with a less than eight percent slope and relief below 30m (labeled A1);

Smooth plains: at least eighty percent of the terrain with a less than eight percent slope and relief between 30 and 90 m (labeled A2);

Irregular plains with slight relief: fifty to eighty percent of the terrain with a less than eight percent slope and relief below 30 m (labeled B1);

Irregular plains: fifty to eighty percent of the terrain with a less than eight percent slope and relief between 30 and 90 m (labeled B2).

The second group includes tablelands with the following four units of predominant convex terrain:

Tablelands with moderate relief: fifty to eighty percent of the terrain with a less than eight percent slope and relief between 90 and 150 m (labeled B3cd);

Tablelands with considerable relief: fifty to eighty percent of the terrain with a less than eight percent slope and relief between 150 and 300 m (labeled B4cd);

Tablelands with high relief: fifty to eighty percent of the terrain with a less than eight percent slope and relief between 300 and 900 m (labeled B5cd);

Tablelands with very high relief: fifty to eighty percent of the terrain with a less than eight percent slope and relief between 900 and 1,500 m (labeled B6cd).

The third group includes plains with hills or mountains with the following four units of predominant concave terrain:

Plains with hills: at least fifty percent of the terrain with a less than eight percent slope and relief between 90 and 150 m (labeled AB3ab);

Plains with high hills: fifty to eighty percent of the terrain with a less than eight percent slope and relief between 150 and 300 m (labeled B4ab);

Plains with low mountains: fifty to eighty percent of the terrain with a less than eight percent slope and relief between 300 and 900 m (labeled B5ab);

Plains with high mountains: fifty to eighty percent of the terrain with a less than eight percent slope and relief between 900 and 1,500 m (labeled B6ab).

The fourth group includes open hills and mountains with the following five landform units:

Open low hills: twenty to fifty percent of terrain with a less than eight percent slope and relief between 30 and 90 m (labeled C2);

Open hills: twenty to fifty percent of terrain with a less than eight percent slope and relief between 90 and 150 m (labeled C3);

Open high hills: twenty to fifty percent of terrain with a less than eight percent slope and relief between 50 and 300 m (labeled C4);

Open low mountains: twenty to fifty percent of terrain with a less than eight percent slope and relief between 300 and 900 m (labeled C5);

Open high mountains: twenty to fifty percent of terrain with a less than eight percent slope and relief between 300 and 900 m (labeled C6).

The fifth group includes hills and mountains with the following four landform units:

Hills: less than twenty percent of terrain with a less than eight percent slope and relief between 90 and 150 m (labeled D3);

High hills: less than twenty percent of terrain with a less than eight percent slope and relief between 150 and 300 m (labeled D4);

Low mountains: less than twenty percent of terrain with a less than eight percent slope and relief between 300 and 900 m (labeled D5);

High mountains: less than twenty percent of terrain with a less than eight percent slope and relief between 900 and 1,500 m (labeled D6).

CHAPTER 4

METHODOLOGY

A simple flowchart of framework is designed to understand the methodology of this dissertation (Figure 4.1). Input data is the LIDAR DEM with 0,25m resolution. Firstly, a buffer polygon is created around the borders of the study area. Buffer distance is specified in a way that should be at least the circle radius value to be used as a search window parameter in classification stage. In this study, since the circle radius was determined as 50 pixels, buffer distance is computed as $[50 \times 0.25 = 12.5\text{m}]$. The reason behind using buffer is addressing the possible problem of edge matching from the view of landforms. In other words, it is aimed to obtain continuous landforms around the neighbor study areas. Then, LIDAR DEM is clipped using buffer polygon, i.e. extended borders of the study area. Using the clipped LIDAR DEM, a primary landform map is obtained in accordance with the methodology proposed by Morgan and Lesh (2005) with some modifications (Section 4.2). Primary landform map is clipped using the borders of the study area. Clipped landform map is converted to polygon. Polygon with the smallest area is determined. Its value is compared to the value of "minimum area" criterion in cartographic generalization. If value of the smallest area in landform map is greater than or equal to value of "minimum area", it means that the landform map is suitable for the specified scale; if not, Focal statistics (Majority) tool is applied to primary landform map to remove small regions while maintaining much of the original spatial pattern, and thus a generalized landform map is obtained. The generalized landform map is clipped using borders of the study area. The clipped landform map is converted to polygon and tested again with respect to "minimum area" criterion. This process is repeated until value of the smallest area in landform map is greater than or equal to value of "minimum area". It should be noted that the test is performed on the clipped landform map rather than the buffered, i.e. primary, landform map, because it is desired to make correct decision considering the smallest polygon just inside the study area. Detailed explanations are given in following sub-sections.

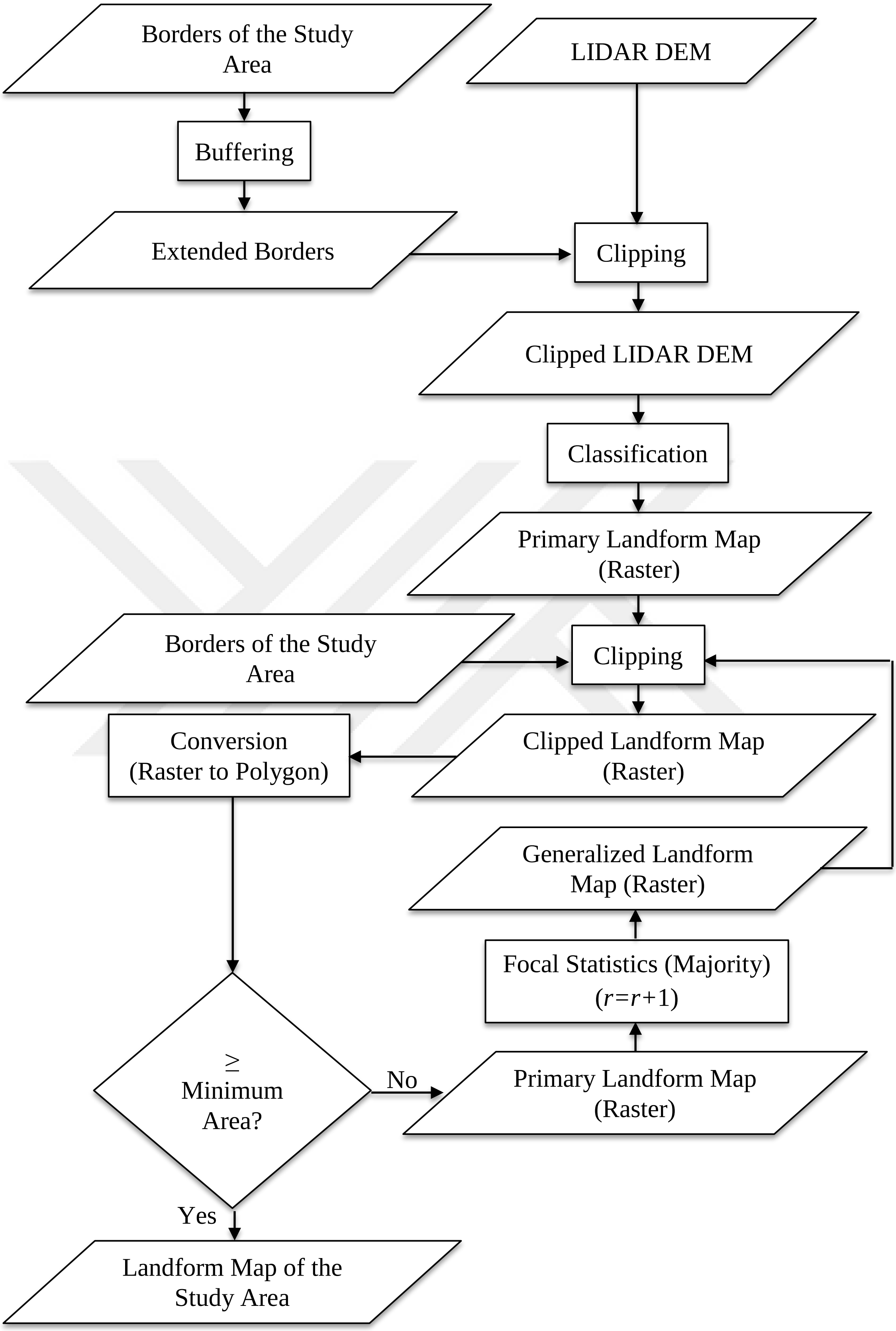

Figure 4.1 Flowchart of the methodology

4.1 Data Source

A very high resolution (0.25m cell size) LIDAR DEM is the main input data in this study (Figure 4.2 and 4.3). Extent of a standard topographic map sheet at 1:1,000 scales (F21-a-20-c-4-b) located near Yeniköy, Eyüp, Istanbul was selected as the study area (Figure 4.4). It is comprised of 2,808 rows and 2,134 columns (i.e. 5,992,272 grid cells) and produced in 2013. Minimum and maximum elevations in the study area are 13.66m and 44.88m, respectively. The main characteristic of this area is that there are several former quarries which are artificial lakes nowadays with darker blue color and there are no residential units as shown in Figure 4.2 and 4.3. It gives us a considerable advantage in validation of the results of this study. This is the reason why we selected this region as the study area. Data was provided by Istanbul Metropolitan Municipality.

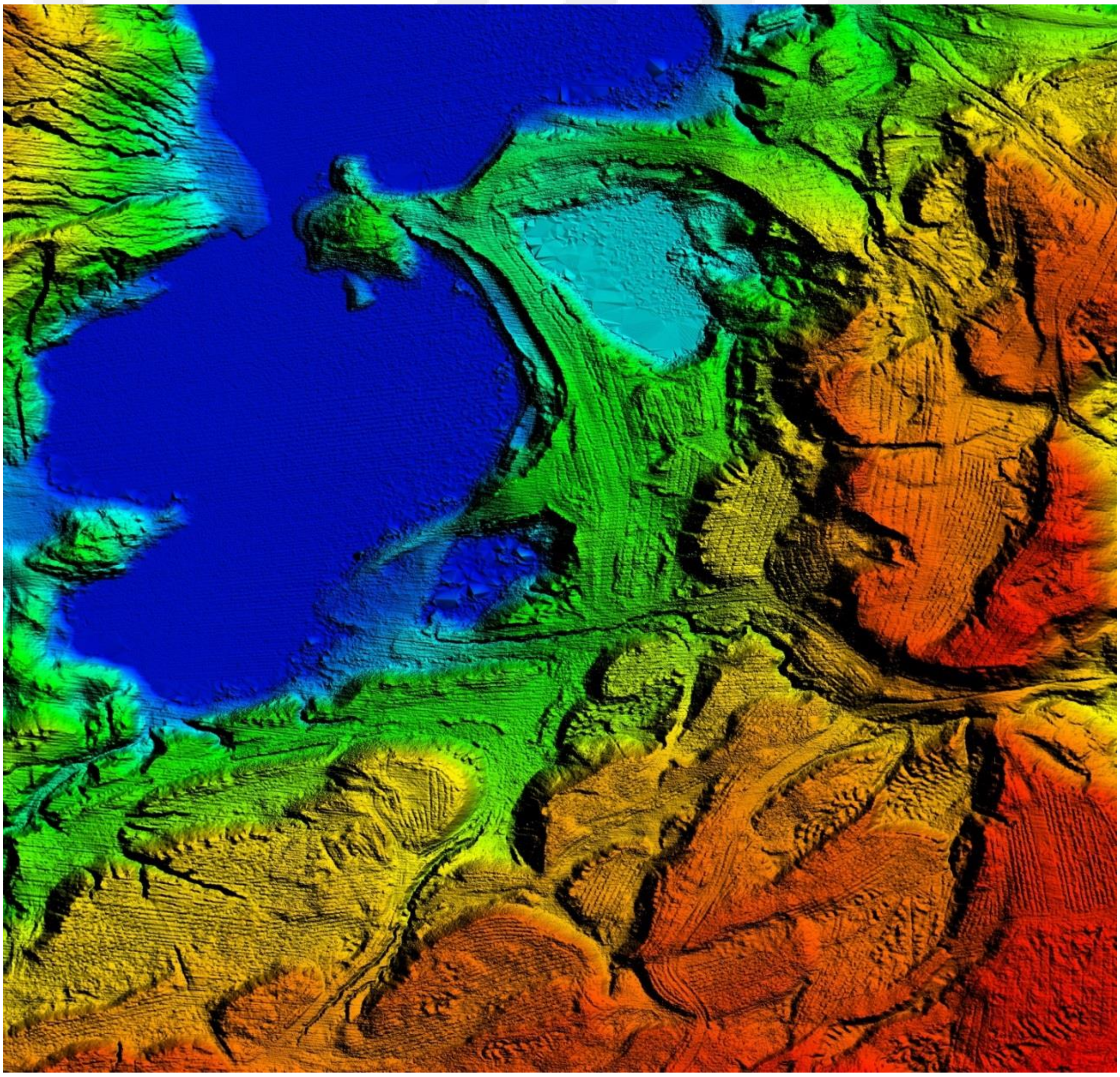

Figure 4.2 LIDAR DEM with 0.25m resolution of the study area

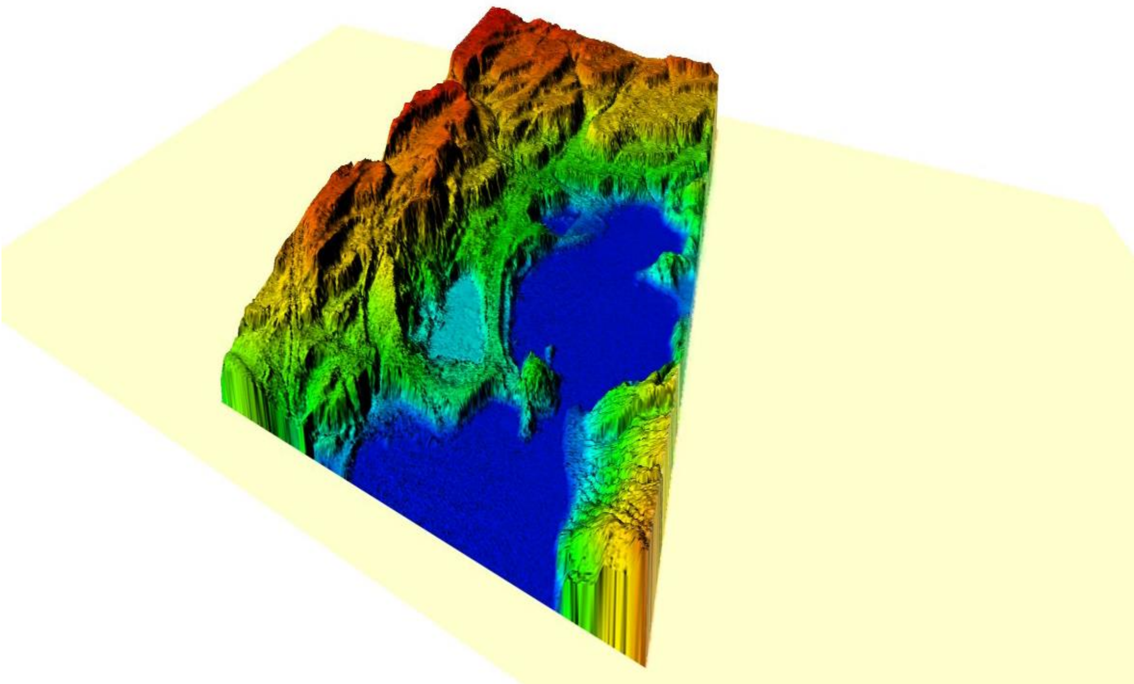

Figure 4.3 Three-dimensional view of the study area

Figure 4.4 Location of the study area

LIDAR (light detection and ranging) is an optical remote-sensing technique that uses laser light to densely sample the surface of the earth, producing highly accurate x, y, z measurements. Lidar, primarily used in airborne laser mapping applications, is emerging as a cost-effective alternative to traditional surveying techniques such as photogrammetry. Lidar produces mass point cloud datasets [13].

The major hardware components of a LIDAR system include a collection vehicle (aircraft, helicopter, vehicle, and tripod), laser scanner system, GPS and INS (inertial navigation system). An INS system measures roll, pitch, and heading of the LIDAR system (Figure 4.5)

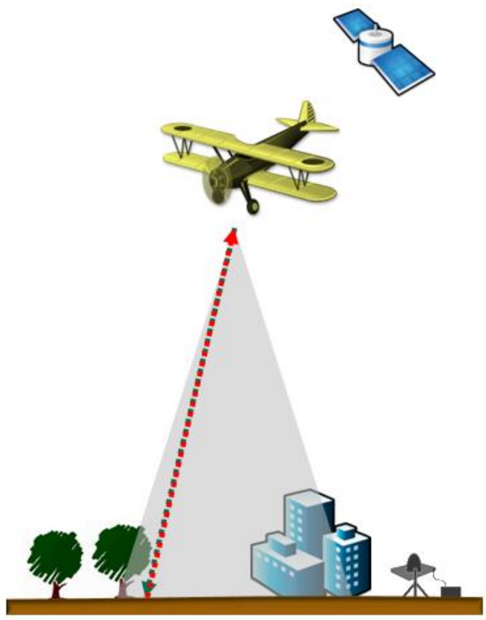

Figure 4.5 LIDAR system [13]

LIDAR is an active optical sensor that transmits laser beams toward a target while moving through specific survey routes. The reflection of the laser from the target is detected and analyzed by receivers in the LIDAR sensor. These receivers record the precise time from when the laser pulse left the system to when it is returned to calculate the range distance between the sensor and the target. Combined with the positional information (GPS and INS), these distance measurements are transformed to measurements of actual three-dimensional points of the reflective target in object space.

The point data is post-processed after the LIDAR data collection survey into highly accurate georeferenced x, y, z coordinates by analyzing the laser time range, laser scan angle, GPS position, and INS information. [13].

4.2 Classification Method

The method developed by Morgan and Lesh (2005) with some modifications was used in landform classification. So many pixels with NoData were occurred in the resulting landform map when 20 pixel was used as radius value of the neighborhood in accordance with Morgan's suggestion. 50 pixel was determined as suitable radius value by trial and error. All pixel in the resulting landform map has no value with NoData only when it was reached to 50 pixel. Furthermore, an interface was developed so that some of the parameters in the model could be changed by the user besides the automation of Morgan and Lesh's workflow (Appendix A). In order to make the slope threshold a model parameter in the interface a logical tool (Greater Than) was used instead of slope reclassification tool in Morgan and Lesh's model.

In accordance with the workflow of Morgan and Lesh's methodology, the analysis is split into three sub-sections, the results from which are then combined to form the final landform classification. The sub-sections are slope, relief and profile, and they are combined to form primary landform type = Slope + Relief + Profile.

The slope map gives the percentage of near-level land for each pixel (which is the value calculated for a 50 pixel radius circular neighborhood and a near-level threshold of 8% slope) split into four classes.

The relief map gives the change in elevation for each cell, based on the maximum and minimum elevation within a 50 pixel radius circular neighborhood.

The profile map gives the percentage of near-level ground in upland and lowland areas of the landscape, again with a 50 pixel radius circular neighborhood. The boundary between upland and lowland is defined as the midpoint between the maximum and minimum elevation for the target pixel's neighborhood (Figure 4.6).

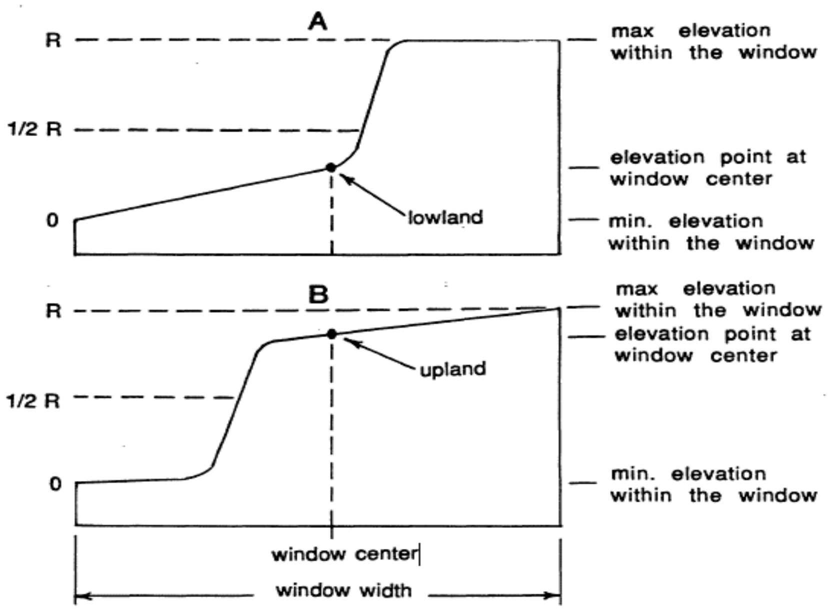

Figure 4.6 The boundary between upland and lowland [3]

Schematic representation of each model, i.e. slope, relief and profile model, is given in Appendix-B. The tools used in these models (Focal Statistics, Reclassify, Slope, Plus, Minus, Float, Divide, Times, and Greater Than) and the working steps are explained in Section 4.2.1 and 4.2.2.

The final landform map is produced by adding together the three sub-section maps.

4.2.1 Tools used in the Model

Focal Statistics

The focal statistics tool performs a neighborhood operation that computes an output raster where the value for each output cell is a function of the values of all the input cells that are in a specified neighborhood around that location. The function performed on the input is a statistic, such as the maximum, average, or sum of all values encountered in that neighborhood (Table 4.1) [14].

Table 4.1 The available Focal Statistics statistics [14]

Mean	Calculates the mean (average value) of the cells in the neighborhood.
Majority	Calculates the majority (value that occurs most often) of the cells in the neighborhood.

Table 4.1 The available Focal Statistics statistics [14](continued)

Maximum	Calculates the maximum (largest value) of the cells in the neighborhood.
Median	Calculates the median of the cells in the neighborhood.
Minimum	Calculates the minimum (smallest value) of the cells in the neighborhood.
Minority	Calculates the minority (value that occurs least often) of the cells in the neighborhood.
Range	Calculates the range (difference between largest and smallest value) of the cells in the neighborhood.
Std	Calculates the standard deviation of the cells in the neighborhood.
Sum	Calculates the sum (total of all values) of the cells in the neighborhood.
Variety	Calculates the variety (the number of unique values) of the cells in the neighborhood.

Conceptually, on execution, the algorithm visits each cell in the raster and calculates the specified statistic with the identified neighborhood. The cell for which the statistic is being calculated is referred to as the processing cell. The value of the processing cell, as well as all the cell values in the identified neighborhood, is included in the neighborhood statistics calculation [14].

The neighborhoods can overlap, so that cells in one neighborhood may also be included in the neighborhood of another processing cell.

The defined neighborhood shapes that can be specified are a rectangle of any dimension, a circle of any radius, an annulus (a doughnut shape) of any radius, and a wedge in any direction (Figure 4.7) [14].

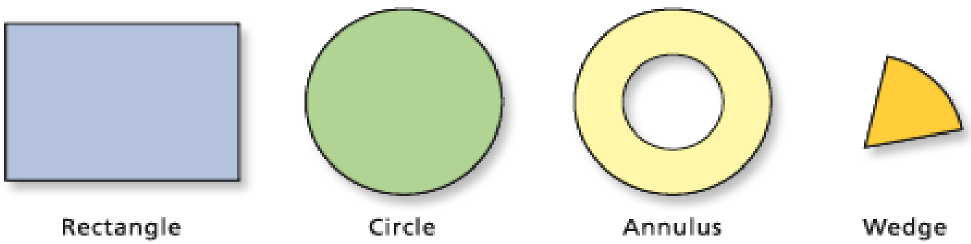

Figure 4.7 Neighborhood shapes [14]

Reclassify

Reclassifies (or changes) the values in a raster. By default, the input raster will be classified into nine classes for the reclassification table. If the input raster is a layer, the old values of the reclassification will be obtained from the renderer. If the renderer is stretched, the reclassification will default to 255 classes [15].

Slope

Identifies the slope (gradient, or rate of maximum change in z-value) from each cell of a raster surface (Figure 4.8) [16].

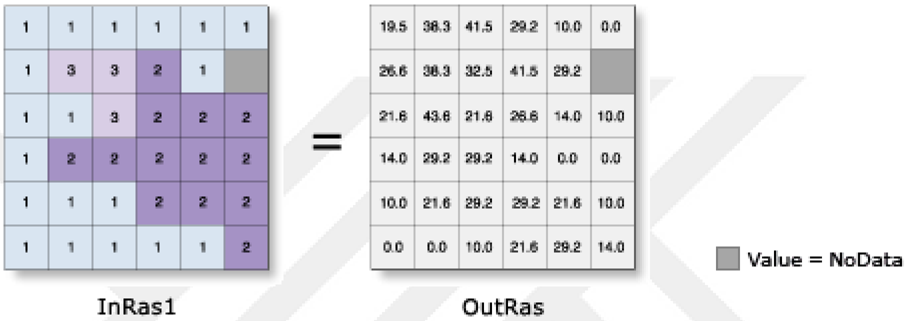

Figure 4.8 Slope calculation [16]

Slope is the rate of maximum change in z-value from each cell. The use of a z-factor is essential for correct slope calculations when the surface z units are expressed in units different from the ground x, y units. The range of slope values in degrees is 0 to 90. For percent rise, the range is 0 for near infinity. A flat surface is 0 percent, a 45 degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly larger [16].

If the center cell in the immediate neighborhood (3x3 window) (Figure 4.9) is NoData, the output is NoData. If any neighborhood cells are NoData, they are assigned the value of the center cell; then the slope is computed.

a	b	c
d	e	f
g	h	i

Figure 4.9 (3x3) window [16]

Slope is commonly measured in units of degrees, which uses the algorithm [16]:

$$slope_{degree} = ATAN\ (\sqrt{([\frac{dz}{dx}]^2 + ([\frac{dz}{dy}]^2))} \times 57.29578\ ^1$$

The rate of change in the x direction for cell e is calculated with the following algorithm:

$$\left[\frac{dz}{dx}\right] = ((c + 2f + i) - (a + 2d + g)) \div (8 \times x_{cellsize})$$

The rate of change in the y direction for cell e is calculated with the following algorithm:

$$\left[\frac{dz}{dy}\right] = \big((g + 2h + i) - (a + 2b + c)\big)/(8 \times y_{cellsize})$$

Divide

Divides the values of two raster on a cell-by-cell basis (Figure 4.10).

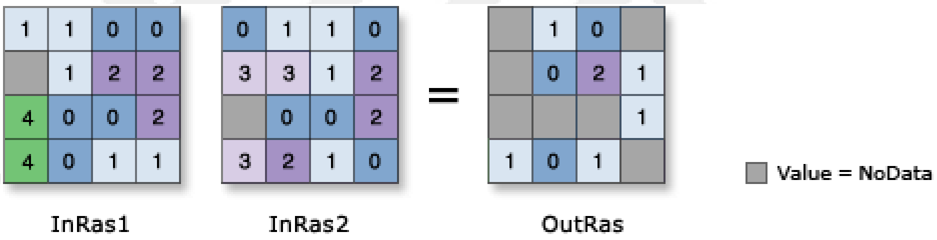

Figure 4.10 Division process [17]

The order of inputs is relevant for this tool. When a number is divided by zero, the output result is NoData. The data types of the inputs to determine the data type of the output: If both inputs are integers, an integer division is performed, and the output result is an integer. For example, if 3 are divided by 2, the output is 1. If either input is floating point, a floating-point division is performed, and the output result is a floating-point value. For example, if 3 are divided by 2.0, the output is 1.5 [17].

Float

Converts each cell value of a raster into a floating-point representation (Figure 4.11).

[1] The value 57.29578 shown here is a truncated version of the result from 180/pi [16].

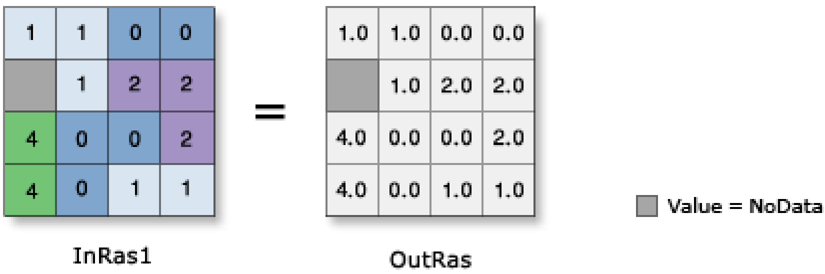

Figure 4.11 Float process [18]

The input values can be positive or negative. If you execute Float on an input that is already floating-point, the output values will remain the same as the input values [18].

Minus

Subtracts the value of the second input raster from the value of the first input raster on a cell-by-cell basis (Figure 4.12).

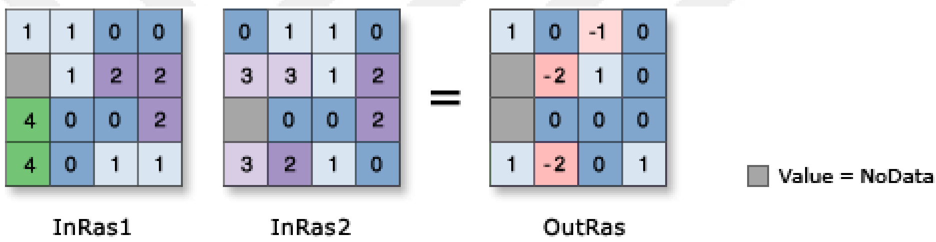

Figure 4.12 Subtraction process [19]

The order of inputs is relevant for this tool. If both inputs are integer, the output will be an integer raster; otherwise, it will be a floating-point raster [19].

Plus

Adds (sums) the values of two rasters on a cell-by-cell basis (Figure 4.13)

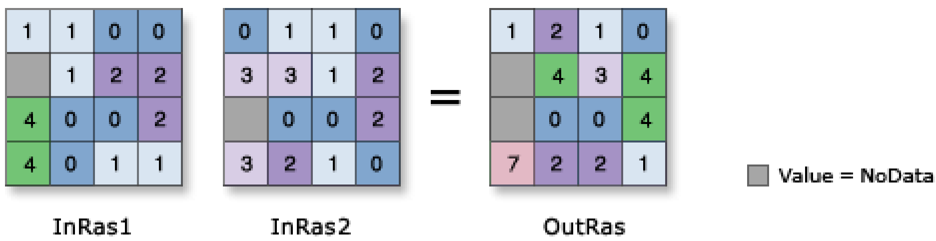

Figure 4.13 Summation process [20]

The order of inputs is irrelevant for this tool. If both inputs are integer, the output will be an integer raster; otherwise, it will be a floating-point raster [20].

Times

Multiplies the values of two rasters on a cell-by-cell basis (Figure 4.14).

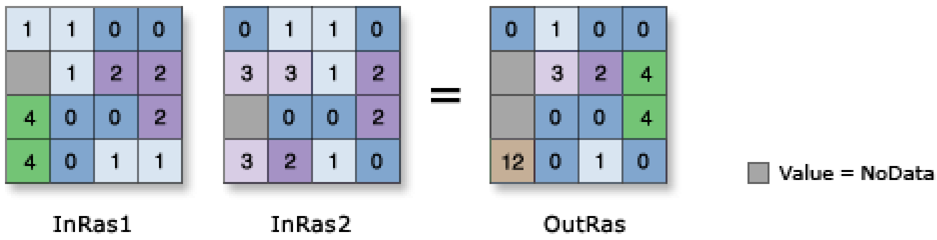

Figure 4.14 Multiplication process [21]

The order of inputs is irrelevant for this tool. If both inputs are integer, the output will be an integer raster; otherwise, it will be a floating-point raster [21].

Greater Than

Performs a relational greater-than operation on two inputs on a cell-by-cell basis. Returns 1 for cells where the first raster is greater than the second raster and 0 for cells if it is not (Figure 4.15).

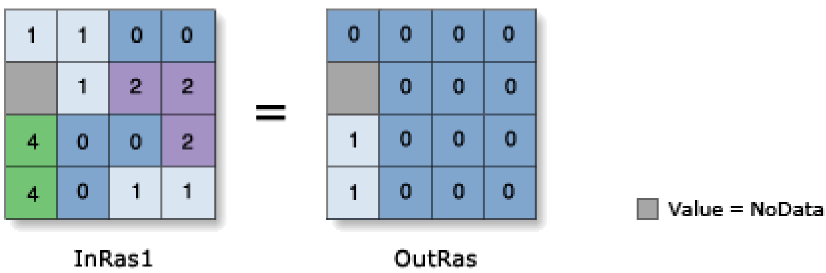

Figure 4.15 Greater Than process [22]

Two inputs are necessary for this relational evaluation to take place. The order of inputs is relevant for this tool [22].

4.2.2 Working Steps in the Model

Classification process is managed in 38 steps as follows.

Step 1: Open ArcCatalog, create new folder with specific name you want, press right click on the created folder, then select New > Toolbox.

Step 2: Press right click on toolbox then select New > Model

Step3: Open model then from the menu bar insert variable then select Raster Layer (the input will be DEM file).

Step 4: Create (Map1) using reclassify tool (Table 4.2):

Input Raster: Clipped LIDAR DEM

Table 4.2 Reclassification of clipped LIDAR DEM

Old Values	**New Values**
-99 – 0	NoData
0 – 9999	1

Output raster: map1

Change missing values to NoData: unchecked

Step 5: Create (map2) using focal Statistics tool as shown below:

Input raster: map1

Output Raster: map2 (also you can change file path)

Neighborhood: Circle

Radius: 50

Statistics type: Sum

Ignore NoData in calculation: checked

Step 6: Create (map3) using float tool as shown below:

Input Raster: map2

Output Raster: map3

Step7: Create (map4) using slope tool as shown below:

Input Raster: Raster Layer (DEM)

Output Raster: map4 (also you can select the file path)

Output Measurement: PERCENT_RISE

Z factor: 1[1]

Step 8: Create (map5) using greater than tool as shown below:

Input Raster or Constant Value 1: 8

Input Raster or Constant Value 2: map4

Output Raster: map5

Step 9: Create (map6) using focal statistics tool as shown below:

Input raster: map5

Output Raster: map6 (also you can change file path)

Neighborhood: Circle

Radius: 50

Statistics type: Sum

Ignore NoData in calculation: checked

Step 10: Create (map7) using divide tool as shown below:

Input Raster or Constant Value 1: map6

Input Raster or Constant Value 2: map3

Output Raster: map7

Step 11: Create (map8) using reclassify tool (Table 4.3).

---

[1] You can change Z factor value to 3.33 if you work in feet.

Input Raster: map7

Table 4.3 Reclassification of map7

Old Values	**New Values**
0 – 0,20	100
0,20 – 0,50	200
0,50 – 0,80	300
0,80 – 1.00	400[1]

Output raster: map8

Change missing values to NoData: unchecked

Step 12: Create (map9) using focal statistics tool as shown below:

Input Raster: Raster Layer (DEM)

Output Raster: map9 (also you can change file path)

Neighborhood: Circle

Radius: 50

Statistics type: Maximum

Ignore NoData in calculation: checked

Step 13: Create (map10) using focal statistics tool as shown below:

Input Raster: Raster Layer (DEM)

Output Raster: map10 (also you can change file path)

Neighborhood: Circle

Radius: 50

Statistics type: Minimum

Ignore NoData in calculation: checked

[1] There is an error in the numbering of these classes in Morgan and Lesh's (2005) publication (pg. 3), noted by Drescher and de Frey (2009). The corrected class numbering is shown here.[23]

Step 14: Create (map11) using minus operation as shown below:

Input Raster or Constant Value 1: map9

Input Raster or Constant Value 2: map10

Output Raster: map11

Step 15: Create (map12) using reclassify tool (Table 4.4).

Input Raster: map11

Table 4.4 Reclassification of map11

Old Values	**New Values**
0 – 30	10
30 – 90	20
90 – 150	30
150 – 300	40
300 – 900	50
900 – 99999	60

Output raster: map12

Change missing values to NoData: unchecked

Step 16: Create (map13) using divide tool as shown below:

Input Raster or Constant Value 1: map11

Input Raster or Constant Value 2: 2

Output Raster: map13

Step 17: Create (map14) using plus tool as shown below:

Input Raster or Constant Value 1: map10

Input Raster or Constant Value 2: map13

Output Raster: map14

Step 18: Create (map15) using minus tool as shown below:

Input Raster or Constant Value 1: map14

Input Raster or Constant Value 2: Raster Layer (DEM)

Output Raster: map15

Step 19: Create (map16) using reclassify tool (Table 4.5).

Input Raster: map15

Table 4.5 Reclassification of map15

Old Values	**New Values**
0 – 99999	1
-9999 – 0	2

Output raster: map16

Change missing values to NoData: unchecked

Step 20: Create (map17) using reclassify tool (Table 4.6).

Input Raster: map16

Table 4.6 Reclassification of map16

Old Values	**New Values**
1	1
2	0

Output raster: map17

Change missing values to NoData: unchecked

Step 21: Create (map18) using times tool as shown below:

Input Raster or Constant Value 1: map17

Input Raster or Constant Value 2: map5

Output Raster: map18

Step 22: Create (map19) using focal statistics tool as shown below:

Input Raster: map18

Output Raster: map19 (also you can change file path)

Neighborhood: Circle

Radius: 50

Statistics type: Sum

Ignore NoData in calculation: checked

Step 23: Create (map20) using float tool as shown below:

Input Raster: map6

Output Raster: map20

Step 24: Create (map21) using divide tool as shown below:

Input Raster or Constant Value 1: map19

Input Raster or Constant Value 2: map20

Output Raster: map21

Step 25: Create (map22) using times tool as shown below:

Input Raster or Constant Value 1: map17

Input Raster or Constant Value 2: map21

Output Raster: map22

Step 26: Create (map23) using reclassify tool (Table 4.7).

Input Raster: map22

Table 4.7 Reclassification of map22

Old Values	New Values
0	0
0,50 – 0,75	2
0,75 – 1,00	1

Output raster: map23

Change missing values to NoData: unchecked

Step 27: Create (map24) using reclassify tool (Table 4.8).

Input Raster: map16

Table 4.8 Reclassification of map16

Old Values	New Values
1	0
2	1

Output raster: map24

Change missing values to NoData: unchecked

Step 28: Create (map25) using times tool as shown below:

Input Raster or Constant Value 1: map24

Input Raster or Constant Value 2: map5

Output Raster: map18

Step 29: Create (map26) using focal statistics tool as shown below:

Input Raster: map25

Output Raster: map26 (also you can change file path)

Neighborhood: Circle

Radius: 50

Statistics type: Sum

Ignore NoData in calculation: checked

Step 30: Create (map27) using divide tool as shown below:

Input Raster or Constant Value 1: map26

Input Raster or Constant Value 2: map20

Output Raster: map27

Step 31: Create (map28) using times tool as shown below:

Input Raster or Constant Value 1: map24

Input Raster or Constant Value 2: map27

Output Raster: map28

Step 32: Create (map29) using reclassify tool (Table 4.9).

Input Raster: map28

Table 4.9 Reclassification of map28

Old Values	**New Values**
0	0
0,50 – 0,75	3
0,75 – 1,00	4

Output raster: map29

Change missing values to NoData: unchecked

Step 33: Create (map30) using plus tool as shown below:

Input Raster or Constant Value 1: map23

Input Raster or Constant Value 2: map29

Output Raster: map30

Step 34: Create (map31) using reclassify tool (Table 4.10):

Input Raster: map30

Table 4.10 Reclassification of map30

Old Values	New Values
0 - 1	1
2	2
3	3
4	4

Output raster: map31

Change missing values to NoData: unchecked

Step 35: Create (map32) using plus tool as shown below:

Input Raster or Constant Value 1: map8

Input Raster or Constant Value 2: map12

Output Raster: map32

Step 36: Create (map33) using plus tool as shown below:

Input Raster or Constant Value 1: map31

Input Raster or Constant Value 2: map33

Output Raster: map33 (also you can change file path)

Step 37: Create (Landform map) using reclassify tool (Table 4.11)

Input Raster: map33

Table 4.11 Reclassification of map33

Old Values	**New Values**
411-414	11
421-424	12
311-321	13
321-324	14
433-434, 333-334	21
443-444, 343-344	22
453-454, 353-354	23
463-464, 363-364	24
431-432, 331-332	31
441-442, 341-342	32
451-452, 351-352	33
461-462, 361-362	34
211-214	41
221-224	42
231-234	43
241-244	44
251-254	45
261-264	46
111-114	51
121-124	52
131-134	53
141-144	54
151-154	55
161-164	56

Output raster: map34

Change missing values to NoData: unchecked

Step 38: Add a labels field to the attribute table for map34 and type in labels (Table 4.12):

Table 4.12 Labels of each code in map34

11	Flat or nearly flat plains

Table 4.12 Labels of each code in map34 (continued)

12	Smooth plains with some local relief
13	Irregular plains with low relief
14	Irregular plains with moderate relief
21	Tablelands with moderate relief
22	Tablelands with considerable relief
23	Tablelands with high relief
24	Tablelands with very high relief
31	Plains with hills
32	Plains with high hills
33	Plains with low mountains
34	Plains with high mountains
41	Open very low hills
42	Open low hills
43	Open moderate hills
44	Open high hills
45	Open low mountains
46	Open high mountains
51	Very low hills
52	Low hills
53	Moderate Hills
54	High hills
55	Low mountains
56	High mountains

4.3 Raster to Polygon Conversion

In order to compute the values of shape area, the clipped landform map (raster) was converted to polygon (vector) by conversion tool. There are two options in this tool as follow:

- SIMPLIFY: The polygons will be smoothed into simpler shapes. The smoothing is done in such a way that the polygons contain a minimum number of segments while remaining as close as possible the original raster cell edges.
- NO_SIMPLIFY: The edge of the polygons will conform exactly to the input raster's cell edges. With this option, converting the resulting polygon feature class back to a raster would produce a raster the same as the original

Figure 4.16 shows how the input raster is vectorised when it is converted to a polygon feature output. The result is presented for both the settings of the simplify parameter [24].

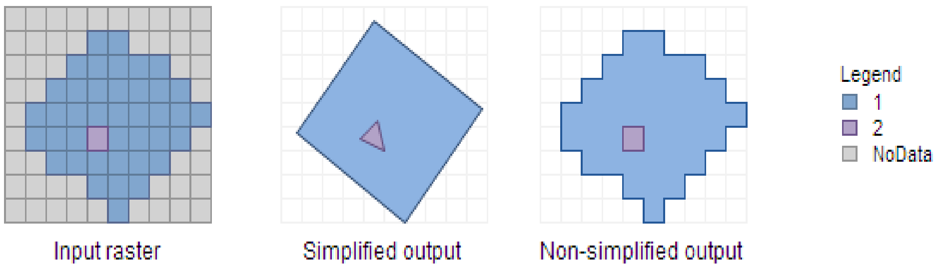

Figure 4.16 Comparing the output of the raster to vector conversion with different simplify options [24]

In this study, the clipped landform map (raster) was converted to polygon (vector) by conversion tool setting the simplify parameter as NO_SIMPLIFY [25].

4.4 Cartographic Generalization Condition: Minimum Area

It is not realistic to continue decreasing the size of map elements down to the just perceptible and printable limits [25].

Reasons for this are:

- Important objects should be immediately obvious, not just perceptible.
- Difference in form should be clearly distinguishable.
- Faint illumination and light printing colours reduce the contrast.

- The best reproduction and printing techniques and equipment are not always available or may not be economical.

Therefore line widths and interspaces in minor landforms should not be less than certain minimal dimensions. For topographic maps and black or very dark printing colours the following value apply:

- 0.3mm side length: Solid Square still distinguishable from a point [25].

As a result, number of pixels corresponding to the minimum area approximately at large and medium scales are computed with respect to the cell size of the source data in this study (i.e. 0,25m) (Table 4.13).

Table 4.13 Minimum area at large and medium scales and number of pixels its correspond

Scale	**Minimum Area (m^2)**	**Number of Pixels**
1:1,000	0.09	2
1:5,000	2.25	36
1:10,000	9.00	144
1:25,000	56.25	900
1:50,000	225	3,600
1:100,000	900	14,400
1:250,000	5625	90,000

Area of one pixel is $[0.25 \times 0.25) = 0.0625\text{m}^2]$. Number of pixels corresponding to minimum area at 1:1,000 is $[0.09 \div 0.0625 = 1.44]$. However, since the clipped landform map (raster) is converted to polygon (vector) by conversion tool setting the simplify parameter as NO_SIMPLIFY and thus pixel based polygon areas are computed, number of pixels corresponding to minimum area at 1:1,000 is assumed 2 as the nearest greater value to computed value 1.44. On the other hand, number of pixels corresponding to minimum area at 1:5,000 is computed as $[2.25 \div 0.0625 = 36]$ directly. Consequently, $[2 \times 0.0625 = 0.125\text{m}^2]$ and $36 \times 0.0625 = 2.25\text{m}^2$ are used as thresholds, i.e. values of minimum area criterion, in the test mentioned in the methodology.

4.5 Focal Statistics (Majority)

A generalization tool applied to landform map (raster) to remove small regions while maintaining much of the original spatial pattern, namely, emphasize trends by eliminating small pockets of unusual values [14]

In order to obtain landforms map at 1:1,000 the following parameters are applied:

Neighborhood: Circle

Radius: 41

Statistics type: Majority

Ignore NoData in calculation: checked

To obtain landforms map at 1:5,000 the following parameters applied:

Neighborhood: Circle

Radius: 9

Statistics type: Majority

Ignore NoData in calculation: checked

[1] These parameters was based on considerable trial-and-error minimum area testing

CHAPTER 5

RESULTS AND DISCUSSION

Minimum area value in the primary landform map was $0.0625m^2$ which was smaller than the threshold, i.e. value of minimum area criterions $0.09m^2$ and $2.25m^2$ for both 1:1,000 and 1:5,000 scales. Therefore, landform maps at 1:1,000 and 1:5,000 were obtained generalizing the primary landform map. When the trails reached 4 circle neiborhood in the focal statistics (Majority) process for generalization of primary landform map, minimum area value in clipped landform map was $1.1875m^2$ which was the nearest greater value than $0.09m^2$, thus the suitable landform map at 1:1,000 was obtained. Similarly, when the trails reached 9 circle neiborhood in the focal statistics (Majority) process for generalization of primary landform map, minimum area value in clipped landform map was 3.125m2 which was the nearest greater value than $2.25m^2$, thus the suitable landform map at 1:5,000 was obtained (Table 5.1).

Table 5.1 Result landform map and minumum area

Result maps	**Minimum area in m^2**
Primary landform map	0.0625
Generalized landform map at 1:1,000	1.1875 > 0.0900
Generalized landform map at 1:5,000	3.1250 > 2.2500

The primary as well as the generalized landform maps at 1:1,000 and 1:5,000 are shown in Figure 5.1, 5.5 and 5.9. In order to evaluate the results, i.e. verify the landforms visually, their hillshaded versions are represented as well in Figure 5.2, 5.6 and 5.10. Furthermore, 2010 dated orthophoto of the study area is used for the same purpose. Landform maps are confirmed by three dimensional views of orthophoto and LIDAR

DEM (Figure 5.3, 5.7 and 5.11). Areas of each landform type in the result maps are given in Figure 5.4, 5.8 and 5.12.

Of twenty-four landform units specified by Morgan and Lesh, only four were distinguished in our study area: irregular plains with low relief open very low hills, very low hills, and flat or nearly flat plains. Since artificial lakes are above sea level, they were indicated as flat or nearly flat plains as well.

The dominate landform in all result maps is open very low hills, followed by very low hills and flat or nearly flat plains with several percentage of the study area. Irregular plains with low releif is the least prevalent (Table 5.2, 5.3 and 5.4).

Table 5.5 has been made in order to see the effect of the generalization on each landform in the primary map.

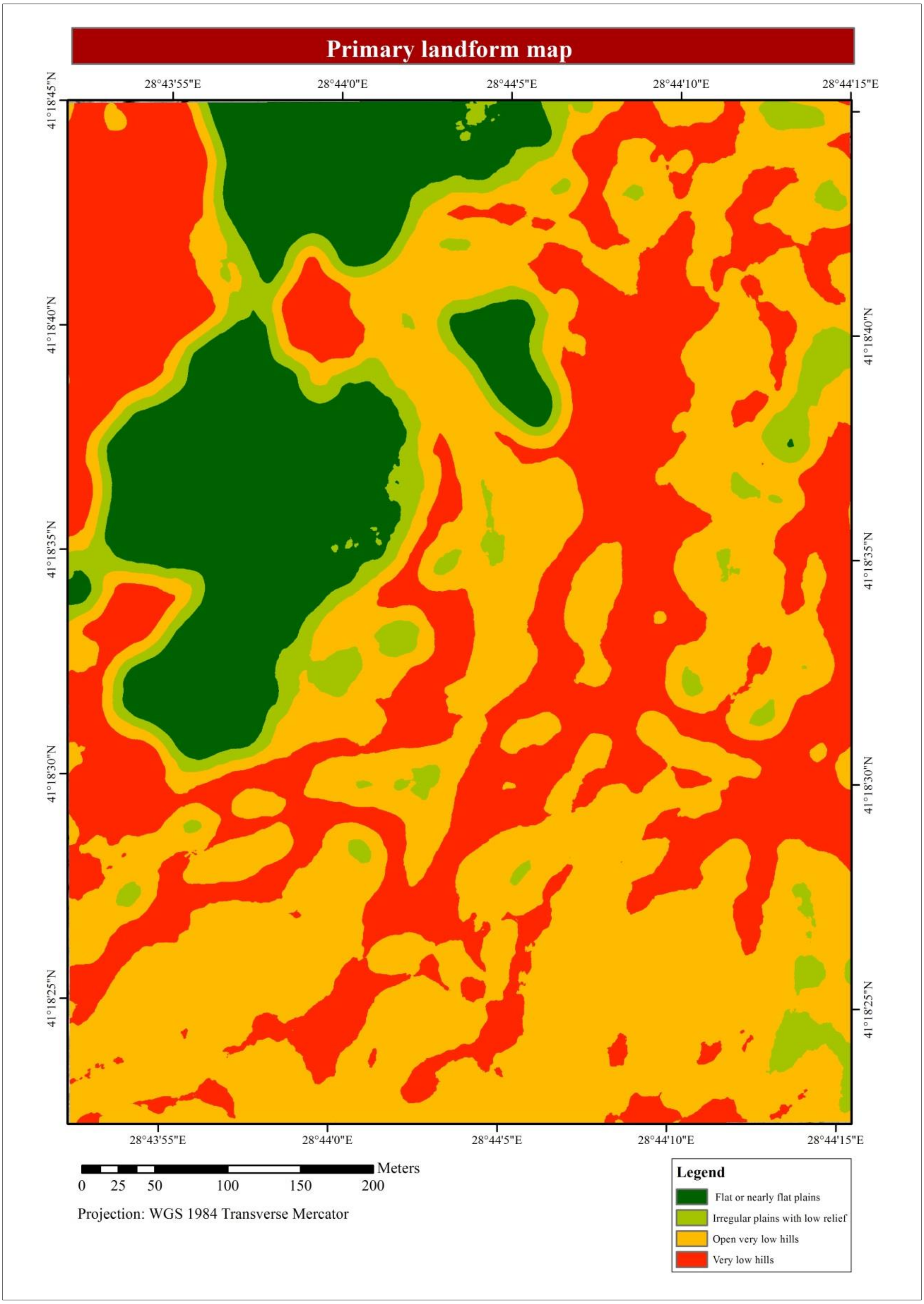

Figure 5.1 Primary landform map

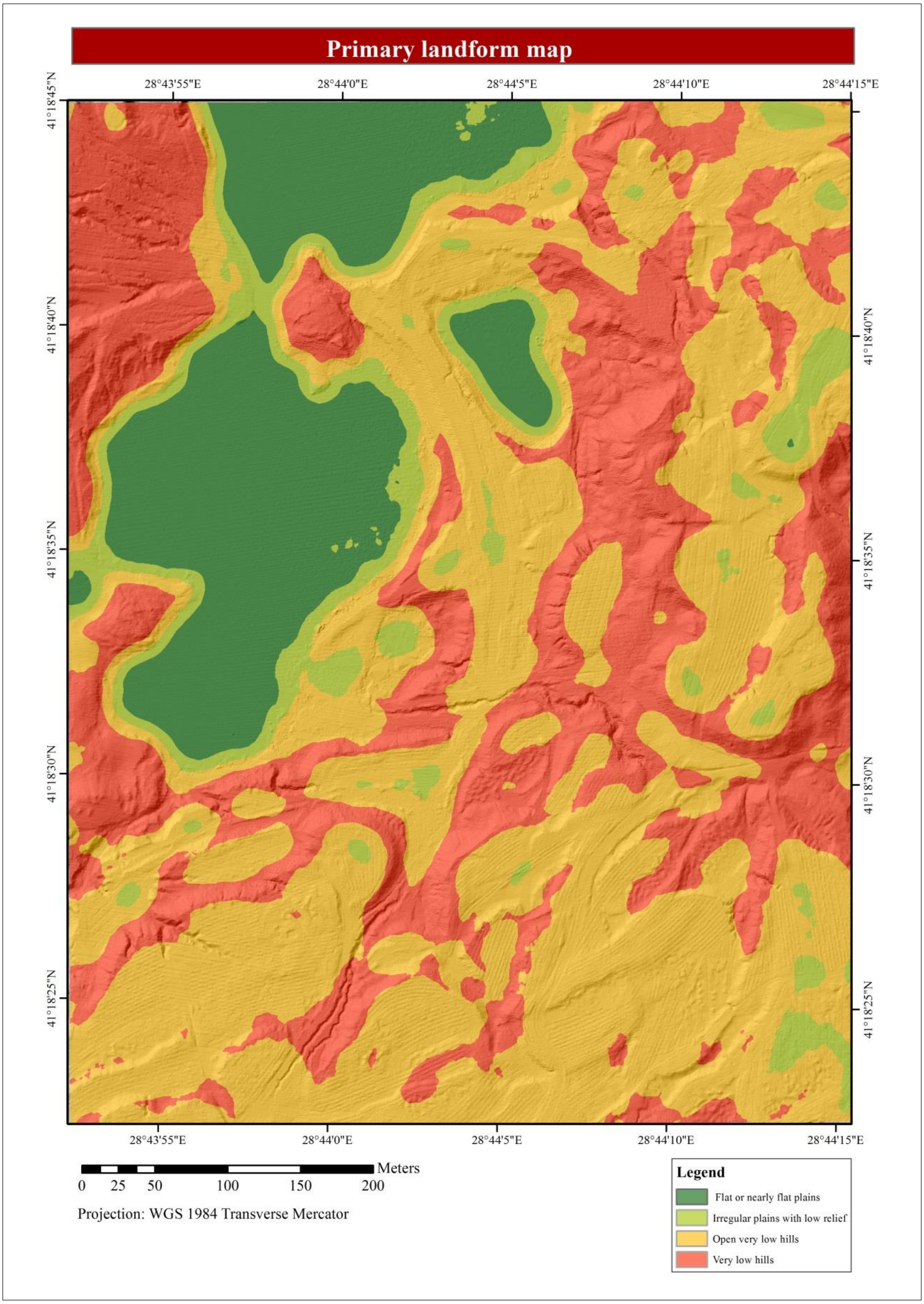

Figure 5.2 Hillshaded primary landform map

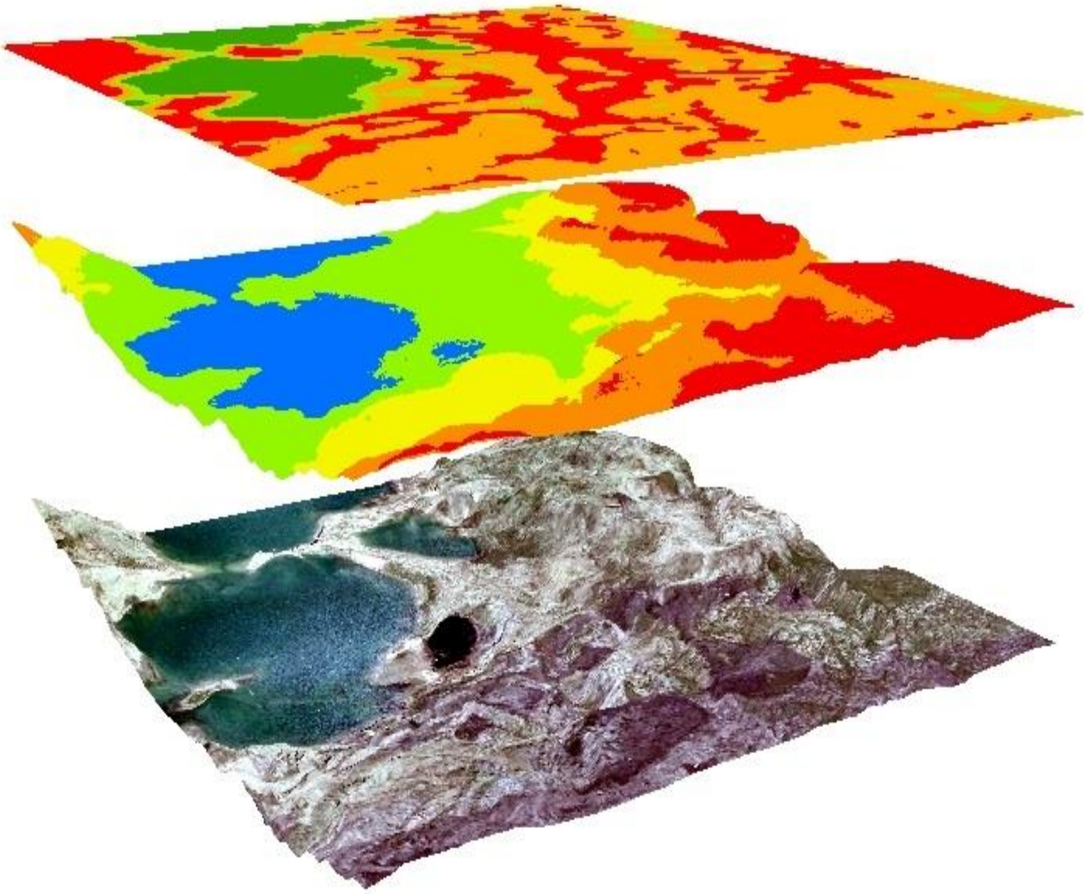

Figure 5.3 Primary landform map (top), LIDAR DEM (middle), orthophoto (bottom)

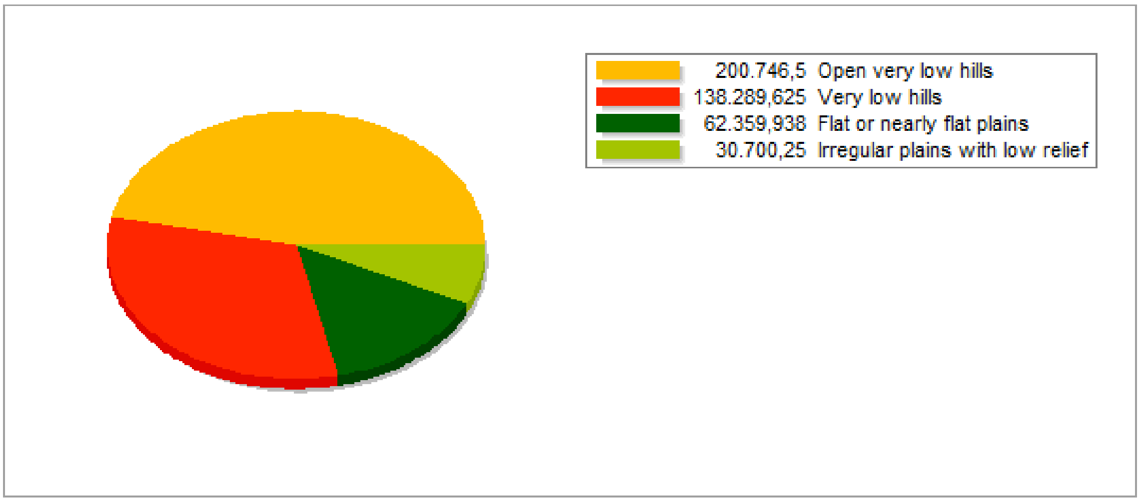

Figure 5.4 Area in meter square for each primary's landform type

Table 5.2 Percentage for each primary landform type

Primary landform types	**Percentage (%)**
Open very low hills	46.46
Very low hills	32.00
Flat or nearly flat plains	14.43
Irregular plains with low releif	7.11

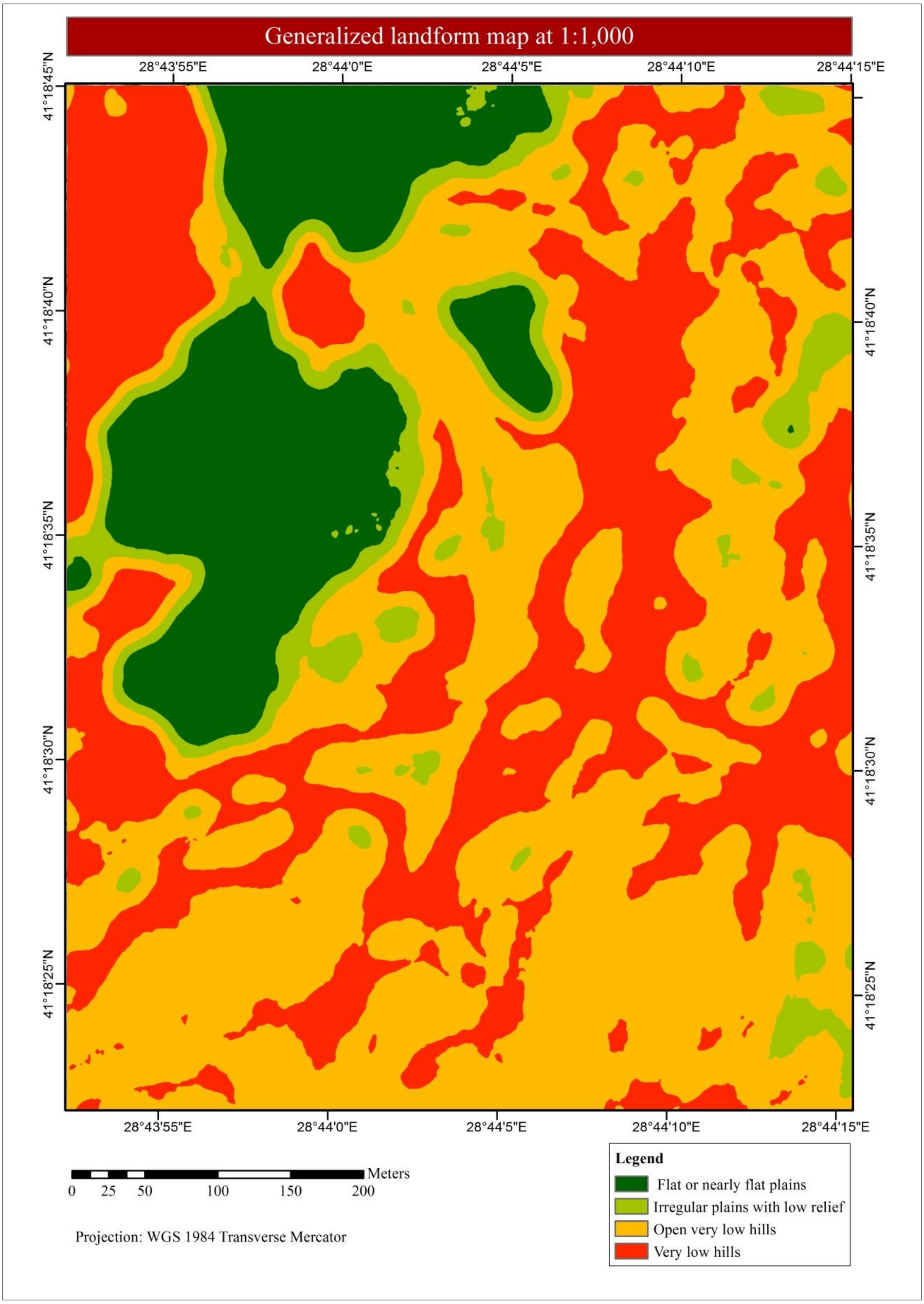

Figure 5.5 Generalized landform map at 1:1,000

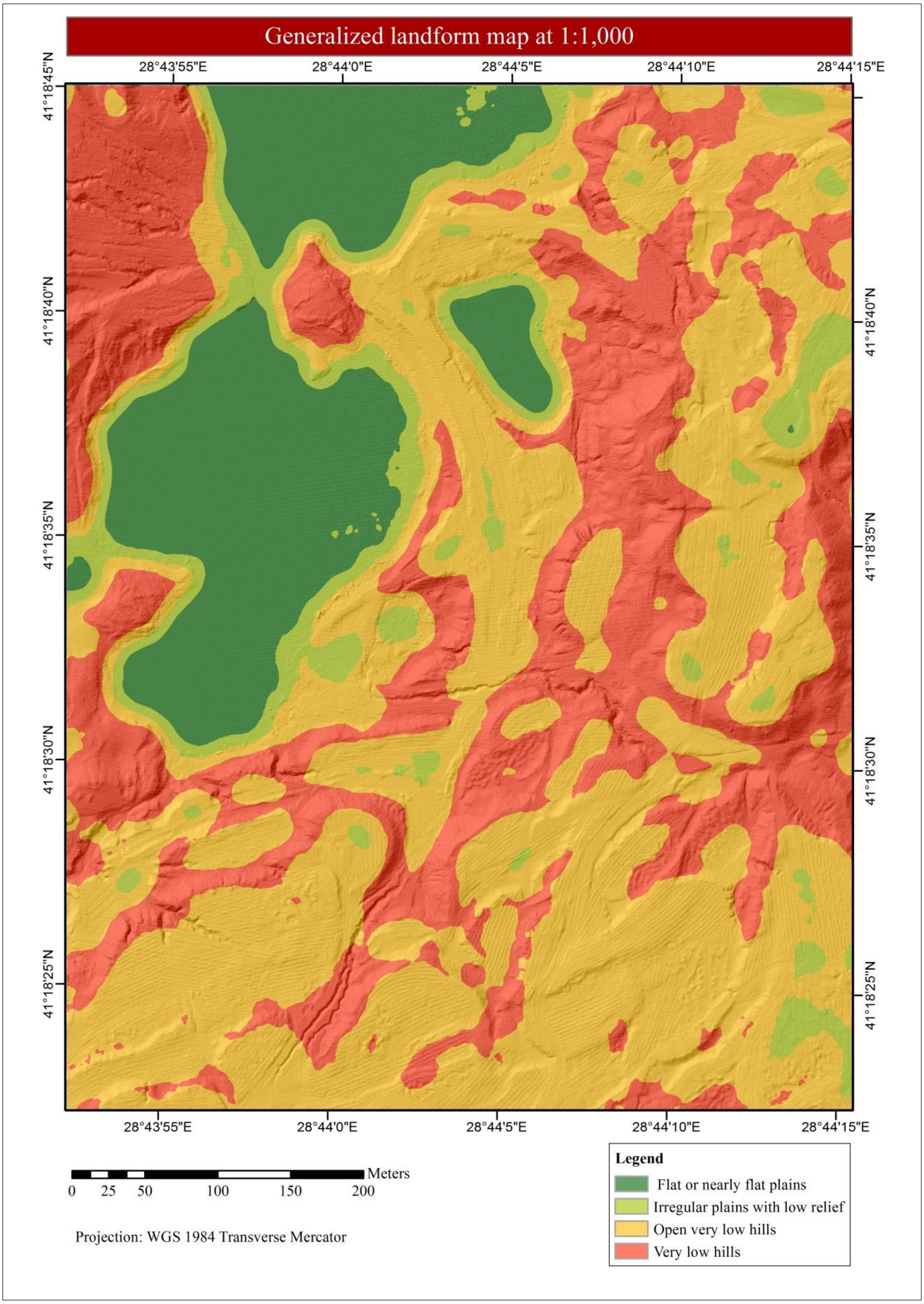

Figure 5.6 Hillshaded generalized landform map at 1:1,000

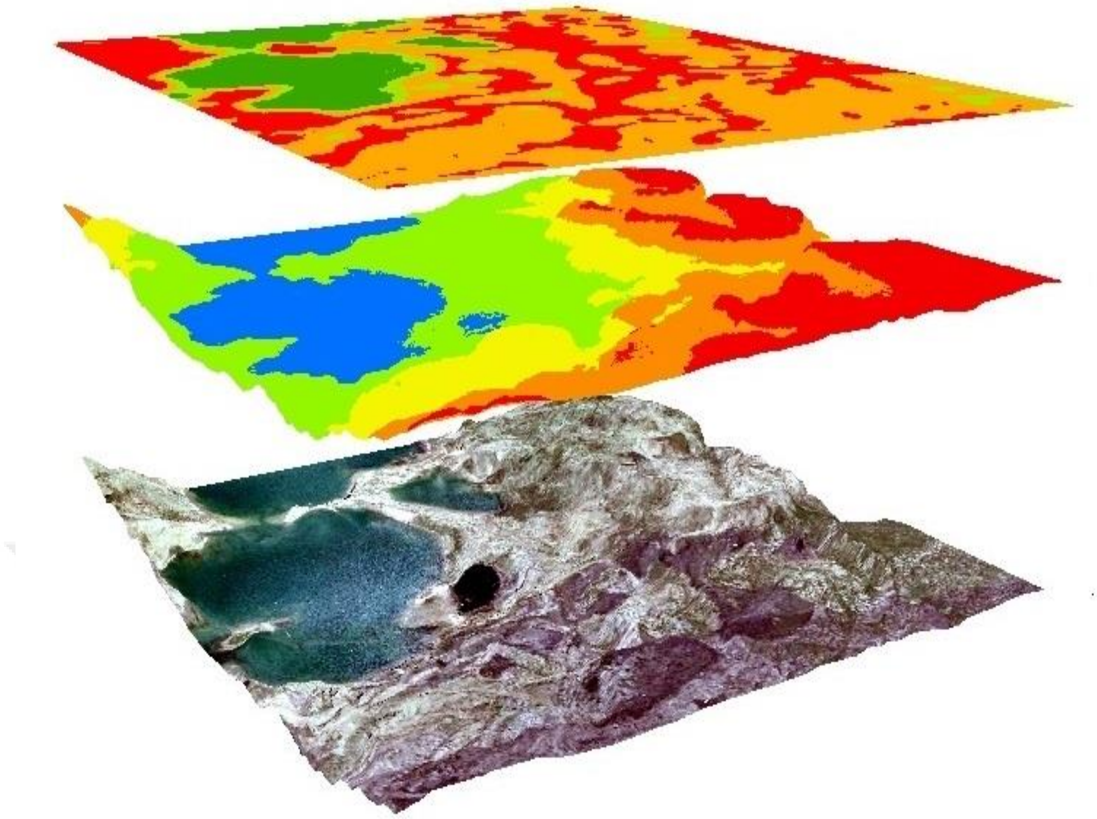

Figure 5.7 Generalized landform map at 1:1,000 (top), LIDAR DEM (middle), orthophoto (bottom)

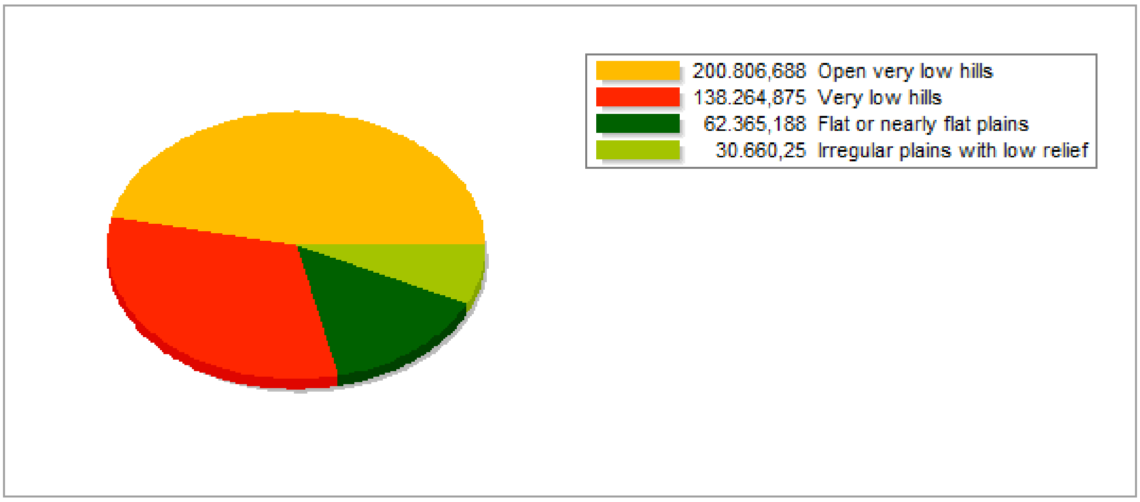

Figure 5.8 Area in meter square for each generalized landform type at 1:1,000 scale

Table 5.3 Percentage for each generalized landform type at 1:1,000 scale

Landform types at 1:1000 scale map	**Percentage (%)**
Open very low hills	46.47
Very low hills	32.00
Flat or nearly flat plains	14.43
Irregular plains with low releif	7.10

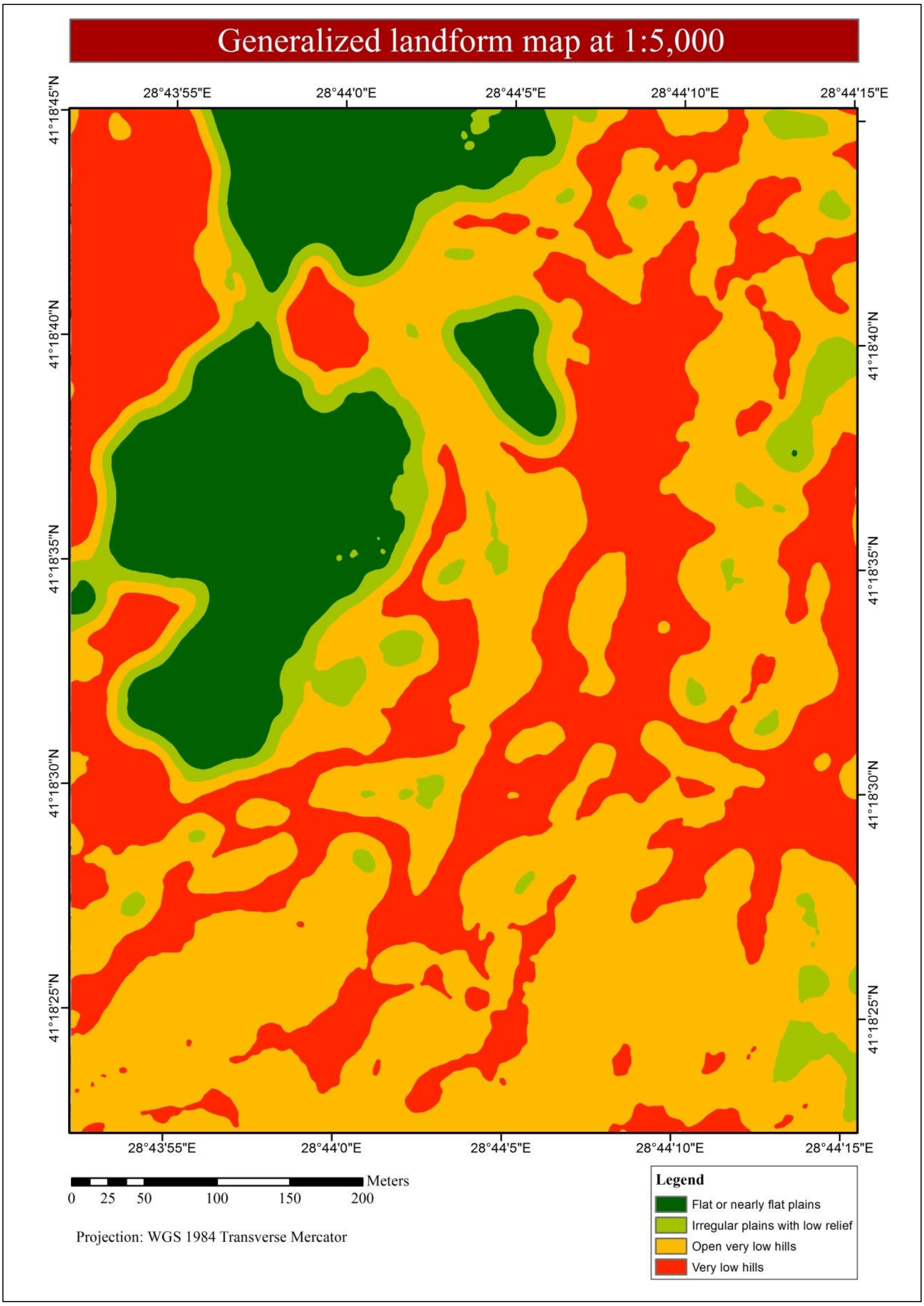

Figure 5.9 Generalized landform map at 1:5,000

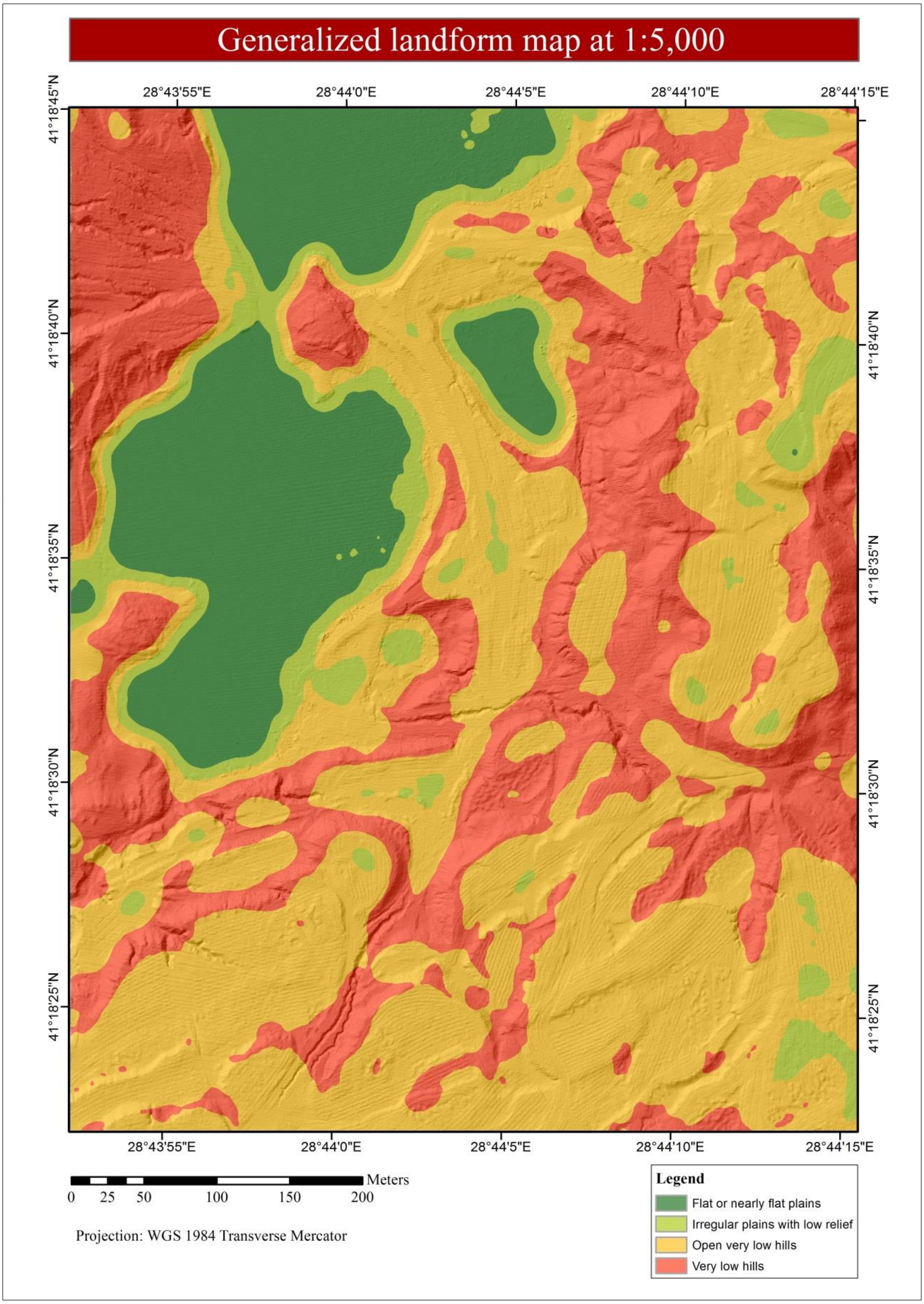

Figure 5.10 Hillshaded generalized landform map at 1:5,000

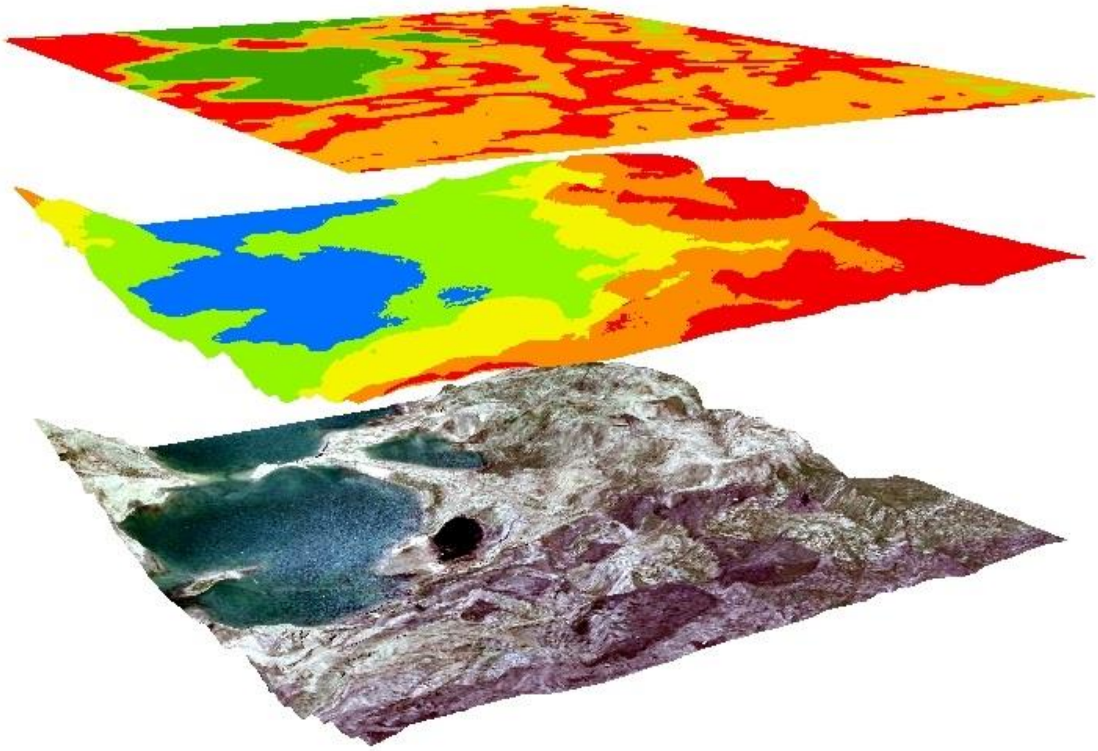

Figure 5.11 Generalized landform map at 1:5,000 (top), LIDAR DEM (middle), orthophoto (bottom)

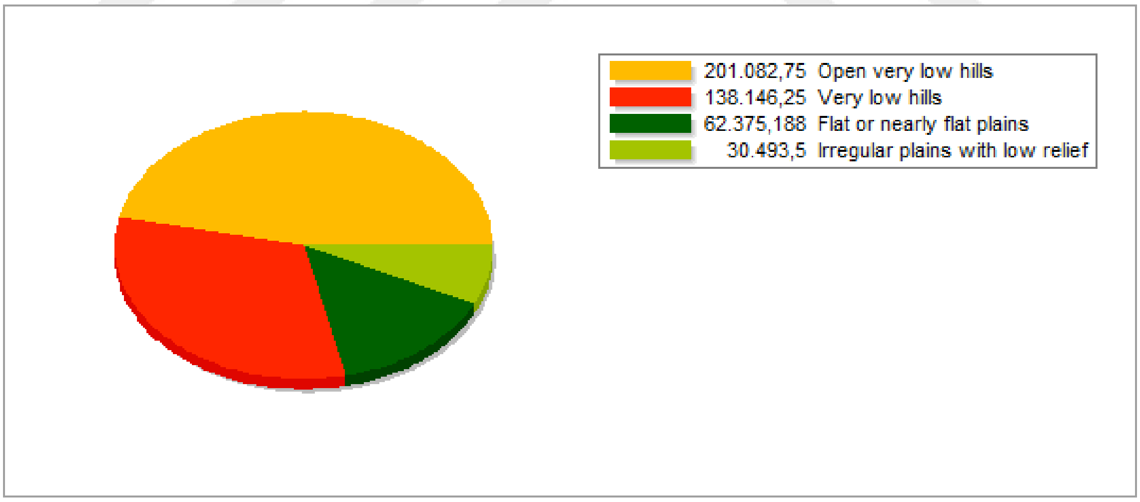

Figure 5.12 Area in meter square for each generalized landform type at 1:5,000 scale

Table 5.4 Percentage for each generalized landform type at 1:5,000 scale

Landform types at 1:5,000 scale map	**Percentage (%)**
Openvery low hills	46.54
very low hills	31.97
Flat or nearly flat plains	14,44
Irregular plains with low relief	7.05

Table 5.5 Area and percentage of each landform type in primary, 1:1,000 and 1:5,000 landform maps

Landform type	**Primary landform map**		**Generalized landform map**			
			1:1,000		**1:5,000**	
	(m^2)	**(%)**	**(m^2)**	**(%)**	**(m^2)**	**(%)**
Open very low hills	200,746.500	46.46	200,806.688	46.47	201,082.750	46.54
Very low hills	138,289.625	32.00	138,264.875	32.00	138,146.250	31.97
Flat or nearly flat plains	62,359.938	14.43	62,365.188	14.43	62,375.188	14,44
Irregular plains with low relief	30,700.250	7.11	30,660.250	7.10	30,493.500	7.05

CONCLUSION

In this study, the main conclusions are as follows.

- LIDAR DEM data could be used for obtaining landform maps at large scales due to its high resolution.
- Since LIDAR DEM data produces very detailed landforms, generalization process is necessary for deriving landforms at specified scales.
- Generalization process could be managed by amalgamating smaller areas recursively.
- Minimum sizes in cartography could be used as a threshold in amalgamation process.
- There is no fixed search window size which is valid for all application in any size of area with any DEM resolution.
- Search window size must be determined for each study depending on the covering area and DEM resolution. However, the user should keep in mind that increasing the size of the search radius will correspondingly increase the time required to process the model.

Furthermore, as it is in this study, there may be a limited range of topographic features due to limited elevation, slope, relief, or profile.

The final landform classification map does not indicate landform elements such as artificial lakes, these features will always need to be added manually to an automatically computed landform map.

An additional note for successful use of Morgan and Lesh’s method is that care must be taken to not use the “Change missing values to NoData” option during the reclassification steps and use of “Ignore NoData in calculations” during focal statistics steps.

REFERENCES

[1] Hammond, E.H., 1954. Small scale continental landform maps. Annals of Association of American Geographers, 44: 32-42.

[2] Hammond, E.H., 1964. Analysis of properties in landform geography: An application to broad scale landform mapping. Annals of Association of American Geographers, 54:11-19.

[3] Dikau, R., Brabb, E.E., Mark, R.M., 1991. Landform classification of New Mexico by computer. In: U.S. Geological Survey, Open-File Report 91-634, 2 sheets, map scale 1:1.000.000, Menlo Park, California.

[4] Dikau, R., Brabb, E.E., Mark, R.M., Pike, R.J., 1995. Morphometric landform analysis of New Mexico. In: Pike, R., Dikau, R. (Eds.), Advances in Geomorphometry. Z. Geomorph., N.F., Suppl.-Bd. 101: 109-126.

[5] Brabyn, L., 1998. GIS analysis of macro landform. In: Firns, P. (Ed.), Proc. 10th Colloquium of the Spatial Information Research Centre. University of Otago, Dunedin, New Zealand.

[6] Morgan, J.M., Lesh, A., 2005. Developing landform maps using ESRI's ModelBuilder. In: Proc. ESRI International User Conference. Available from: http://proceedings.esri.com/library/userconf/proc05/papers/pap2206.pdf. Accessed 20 January 2014.

[7] Gallant, A.L., Brown, D.D., Hoffer, R.M., 2005. Automated mapping of Hammond's landforms. IEEE Geoscience and Remote Sensing Letters, 2(4): 384-388.

[8] Hrvatin, M., Perko, D., 2009. Suitability of Hammond's method for determining landform units in Slovenia. Acta geographica Slovenica, 49(2):343–366.

[9] Merina, A.P., Perucho, M.A., Ruiz, M.A., Guerrero, I.C., 2011. Landform of Alicante province by using GIS. In: Concheri, G., Meneghello, R., Savio, G. (Eds.), Proc. International Conference on Innovative Methods in Product Design, San Servolo, Venice, Italy.

[10] Williams, M., Kuhn, W., Painho, M., 2012. The influence of landscape variation on landform categorization. Journal of Spatial Information Science, 5: 51–73.

[11] MacMillan, R.A., Shary, P.A., 2009. Landforms and Landform Elements in Geomorphometry. In: Hengl, T., Reuter, H.I. (Eds.), Geomorphometry: Concepts, Software, Applications. Developments in Soil Science, Vol. 33, Elsevier, Hungary.

[12] Mr.Lovera's virtual classroom, classblog, http://www.mrlovera.org/apps/blog, 17 July 2014

[13] Esri, What is lidar data, http://resources.arcgis.com/en/help/main/10.2/index.html#//015w00000041000000, 18 April 2014

[14] Esri, Focal Statistics (Spatial Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#//009z000000qs000000, 18 July 2014

[15] Esri, Reclassify (Spatial Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#//009z000000sr000000, 18 July 2014

[16] Esri, Slope (Spatial Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#//009z000000vz000000, 18 July 2014

[17] Esri, Divide (Spatial Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#//009z0000008r000000, 18 July 2014

[18] Esri, Float (Spatial Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#/Float/009z0000008w000000/, 18 July 2014

[19] Esri, Minus (Spatial Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#/Minus/009z00000093000000/, 18 July 2014

[20] Esri, Plus (Spatial Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#/Plus/009z00000096000000/, 18 July 2014

[21] Esri, Times (Spatial Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#/Times/009z0000009p000000/, 18 July 2014

[22] Esri, Greater Than (Spatail Analyst), http://resources.arcgis.com/en/help/main/10.1/index.html#//009z000000m5000000, 18 July 2014

[23] Drescher, K., and Frey, W. D., 2009. Landform classification using GIS, Position IT.

[24] Esri, Raster to Polygon (Conversion), http://resources.arcgis.com/en/help/main/10.1/index.html#/Raster_to_Polygon/001200000008000000/, 18 July 2014

[25] Rytz, A., Bantel, E., Hoinkes, C., Merkle, G., Schelling, G., 1975. Kartographische Generalisierung: Topographische Karten. Kartographische Schriftenreihe Herausgegeben von der Schweizerischen Gesellschaft für Kartographie, No. 1, Zürich.

APPENDIX-A

LANDFORM CLASSIFICATION INTERFACE

Figure A.1 Landform classification interface

APPENDIX-B

MORGAN AND LESH LANDFORM CLASSIFICATION

The following four Model Builder models were used to perform the landform classifications according to the steps outlined in Morgan and Lesh (2005) with some modification.

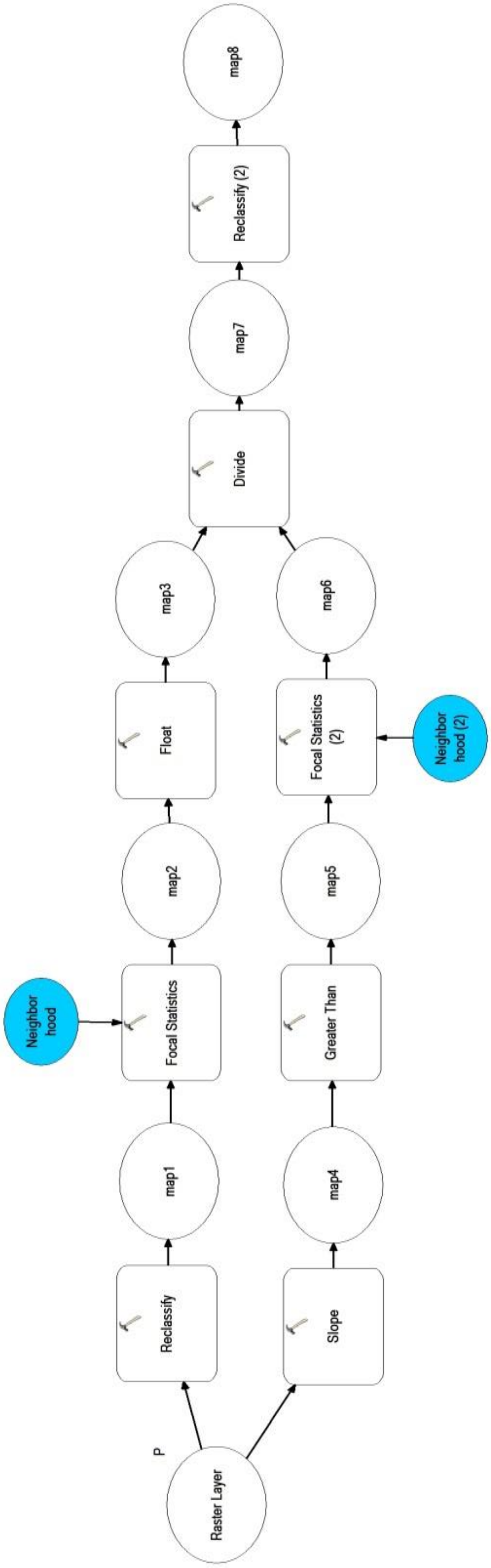

Figure B.1 Slope sub-model

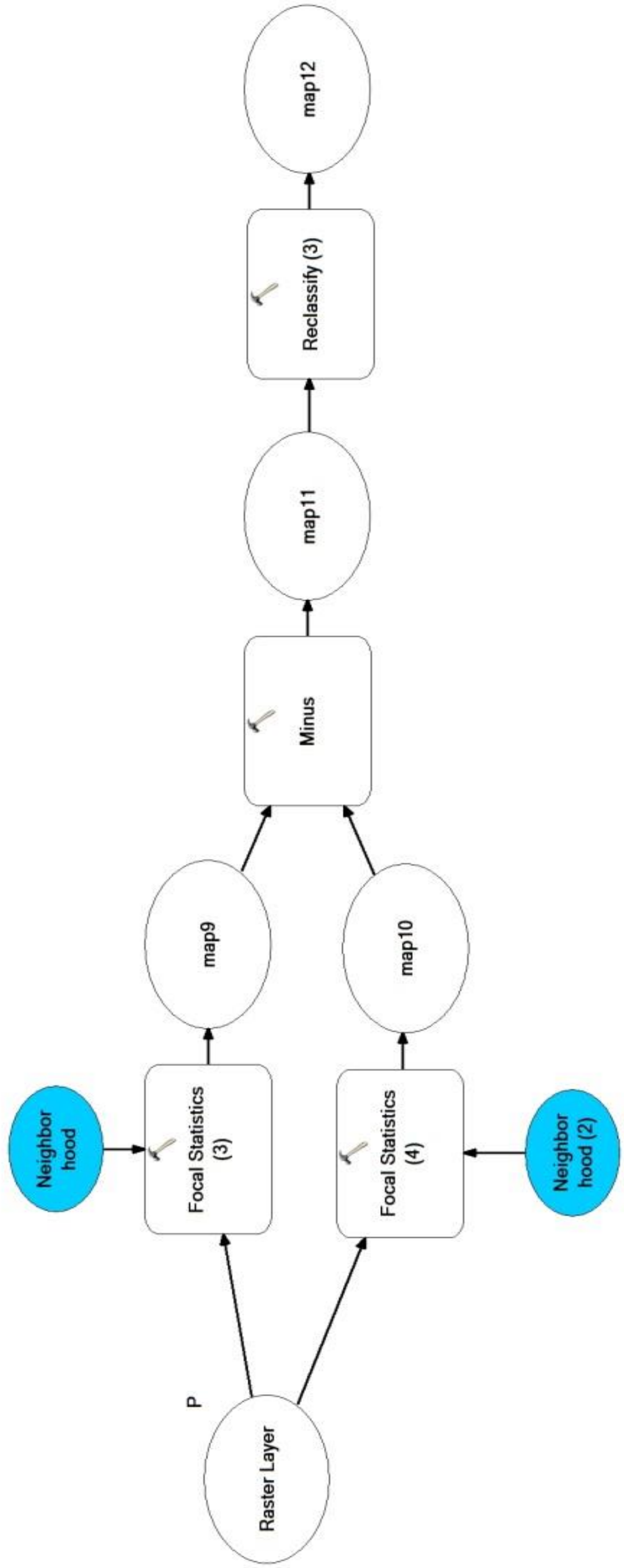

Figure B.2 Relief sub-model

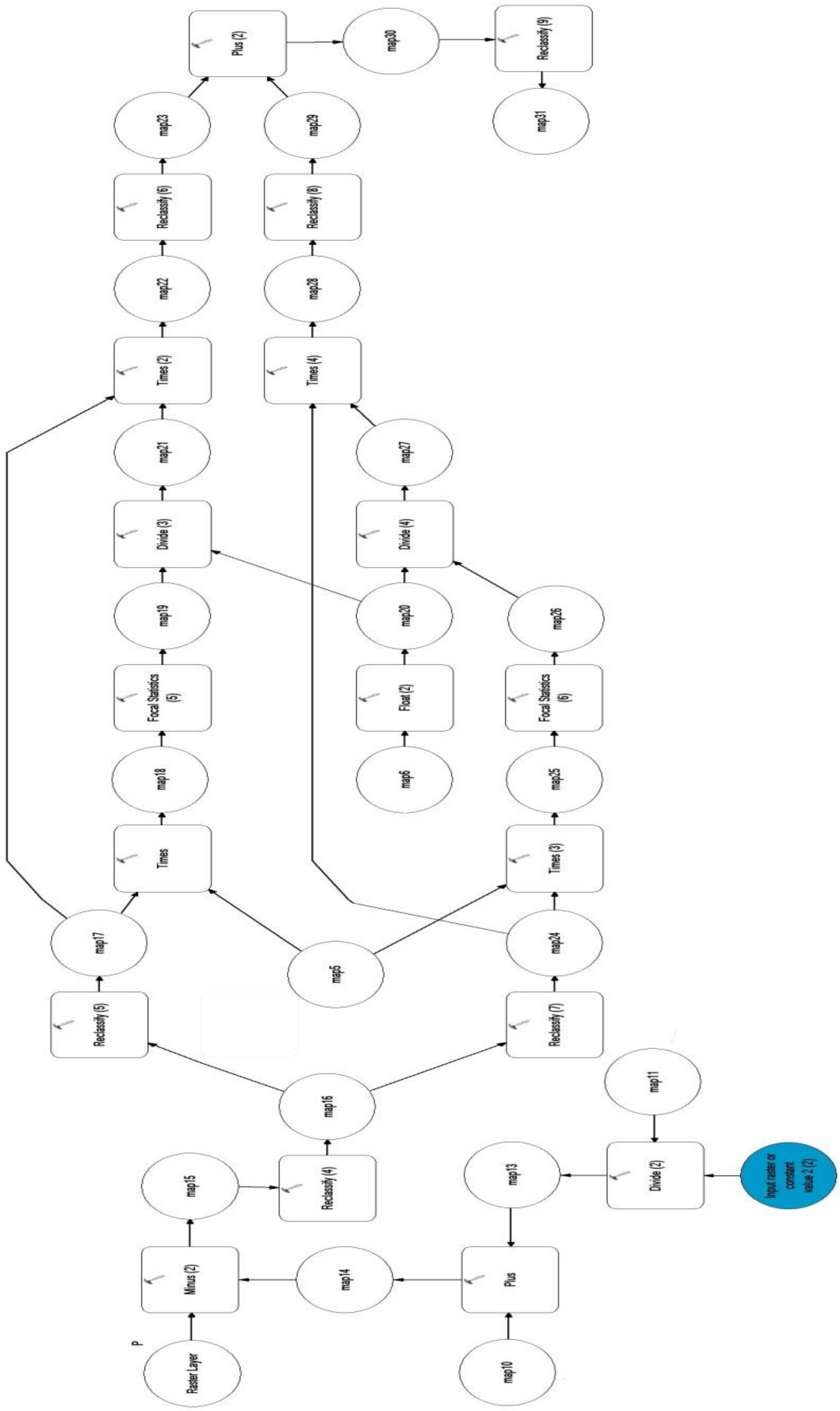

Figure B.3 Profile sub-model

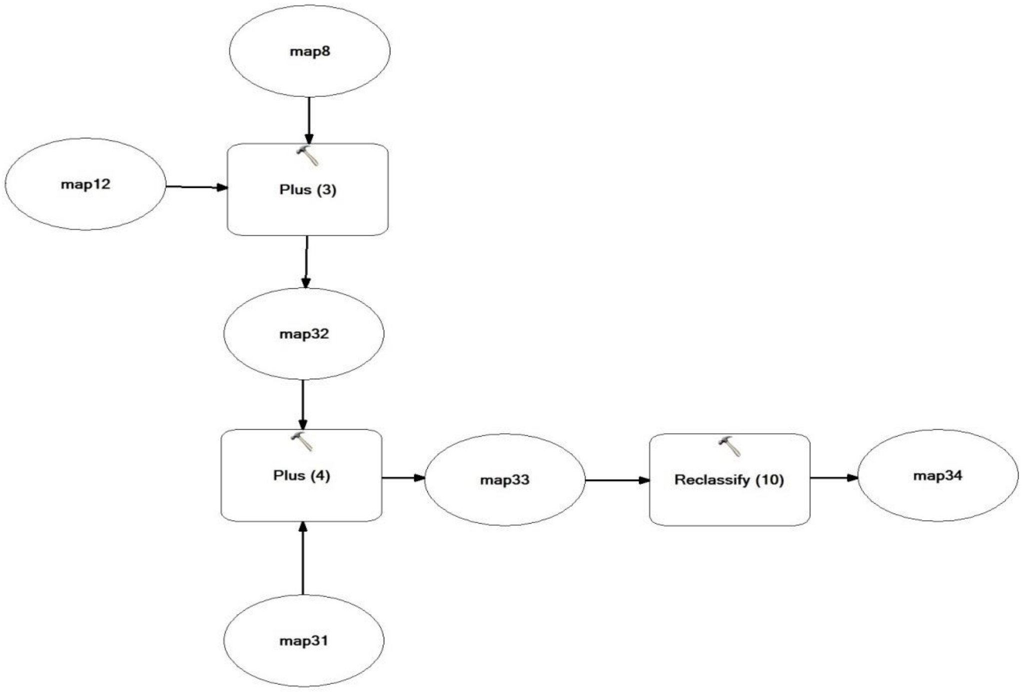

Figure B.4 Final classification

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