

# GIS ON DRAINAGE SYSTEM QUANTITATIVE ANALYSIS

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In a drainage system study, one of the metrology methods is the use of the *three Horton Laws*, plus the calculation of *frequency* and *density*. Although these calculations need very simple mathematical operations, they present a lot of problems that force scientists to achieve a result of reduced accuracy.

The first problem is the vast number of simple calculations that need to be repeated thousands of times in order to cover all the branches and basins of the drainage system. A second problem arises when there is a need for the measurement of very small distances and very small basin areas. In such cases, the equipment's tolerance is quite large compared to the actual produced number. Finally, a third problem that arises is the large amount of time that one needs to draw all the necessary color maps.

This study, intends to increase accuracy, and speed up these elementary, but time consuming operations, allowing scientists to spend more time on the interpretation, than on the estimation of the numbers.

In this paper, we will describe a GIS based methodology, and then apply it on Jirorema torrent (South Peloponeese, Kalamata) and the basins formed by the 901 Stream sub-branches that are related to it.

## **K-words.**

- G.I.S.
- Geomorphology
- Numeric analysis

## **The aim of the study**

This paper describes a methodology on drainage system quantitative analysis. Jirorema torrent, was selected among others because of:

1. The large number of its branches
2. The existence of very short branches
3. The existence of very small basins
4. The tectonic influence on the Jirorema drainage system

## **Brief Geological description of the area (Geological setting of the area)**

The area of Jirorema basin is consisted mainly of limestones (82,92%). The dolomitic limestones of the Tripoli's zone (Cretaceous), occupy the 55,84% of all the

limestones. The undivided flysch of Tripoli's zone (Upper Eocene/Oligocene) occurs in a smaller percentage. Figure 1 shows the geological map of the area.

Generally three lithological units appear in Jirorema's basin: Quaternary deposits, Flysch and Limestones as shown in figure 2.

The outer Jirorema area is situated at the south part of the big tectonic depression of 'Kiparisia-Kalamata'. The whole area is seismologically very active, due to the neighboring tectonic trench. The drainage system is reflecting the tectonic movements the area is frequently submitted to.

### **Basic initial steps**

To digitize the whole drainage system (Stream branches and basins) of the studied area we used the topographic maps (scale 1:50.000). The produced map, is shown in figure 3, with the Streams in blue and the basin borders in green. The precision achieved with the digitization is very good, because of the zooming capabilities of the GIS system. Using the zoom tool, the user can enlarge as many times as necessary the working area and digitize in great detail. Practically the digital outcome of this procedure is identical to the topographic map. Therefore the precision is based on the accuracy provided from the original map.

Having the drainage system digitized, the next step is to number the Stream branches and basins. The branches are numbered circularly providing one number for the class and one for the position of each branch. All the basins are auto-numbered. Each one retrieves the class and position number of the included branch.

### **Calculating the three Horton's Rules**

#### **First Horton's rule :**

$$Rb = \frac{N_u}{N_{u+1}} \text{ (equation 1)}$$

$$N_u = \overline{Rb}^{(k-u)} \text{ (equation 2)}$$

This rule uses equation 1, to produce the ratio  $R_b$ , called branch ratio, from the division of the total number of Streams in a  $u$  class ( $N_u$ ), with the total number of Streams in the next upper class ( $N_{u+1}$ ).

This Stream count is automatically given from the GIS, either by a simple aggregation SQL statement with class number and count columns, or with a

thematic map (with the count feature on) representation where each Stream has a color depending on its class (figure 4).

From the calculated ratios, using equation 2 ( $k$  is the maximum class), we can estimate the ideal number of branches ( $N_u$ ) for each class, and the deviation of the ideal values from the real ones.

The comprehensive results of the first rule are in the next table:

Class	Real branch count	$R_b$	$\overline{Rb}$	Ideal branch numbers	Deviation %
1	686	4,29	3,98	996	-31,12
2	160	4,10		250	-36
3	39	3		63	-38,10
4	13	6,5		16	-18,75
5	2	2		4	-50
6	1			1	0

**Second Horton's rule :**

$$R_L = \frac{\overline{L_u}}{\overline{L_{u-1}}} \text{ (equation 3)}$$

$$\overline{L_u} = \overline{L_1} * R_L^{(u-1)} \text{ (equation 4)}$$

In the second Horton's rule, we used the accumulated Stream lengths of each class, and according to the equation 3 and 4, we calculated the expected Stream lengths in the ideal condition and the deviations of the real values.

In order to measure the accumulated lengths, we added a new column to the Stream browser, and updated it with the lengths of each branch. After that, using the SQL language, we asked for two columns: class and aggregated Stream length, as shown in the next two lines:

**SQL clause:**

Select Class, Sum(length) from JerStreams group by Class order by Class into Selection  
Browse \* From Selection

Using these data, we came to the following table:

Class	Real accumulated lengths	$R_L$	$\overline{R_L}$	Ideal acumulated lengths	Deviation %
1	251,31	4,28	4,23	251,31	0
2	1.076,19	4,73		1.063,03	1,24
3	5.093,71	3,48		4.496,61	13,28
4	17.722,45	5,26		19.020,66	-6,83
5	93.140,16	3,42		80.457,41	15,76
6	318.193,50			340.334,85	-6,51

**Third Horton's rule :**

At the third Horton's rule, we have to follow exactly the same steps, but instead of lengths, we use areas of the basins. The equations which are used, are the same with the ones used for the second rule, and the SQL statement is the same if we change the 'length' measurement into 'area'. The results are in the next table:

Class	Accumulative Numbers	R <sub>A</sub>	$\overline{R_A}$	Ideal Numbers	Deviation %
1	70.506,31	4,07	4,22	70.506,31	0
2	287.048,44	4,82		297.536,63	-3,53
3	1.383.899,31	3,32		1.255.604,57	-10,22
4	4.600.526,28	5,29		5.298.651,29	-13,18
5	24.350.265,11	3,58		22.360.308,44	8,90
6	87.099.529,34			94.360.501,63	-7,69

### Drainage Frequency Calculation

$$F_u = \frac{\sum N_u}{A_u} \quad (\text{equation 5})$$

The drainage frequency is a number, calculated for each basin separately, that indicates the quantity of Stream branches compared to the area of their basin. The mathematical equation (equation 5) uses the total number of branches in a basin (for the first class the  $\sum N_u$  is always 1) divided by the area of the basin ( $A_u$ ).

The GIS system is able to find automatically the total number of Streams included in each basin and store it in a new column, next to the basins ID numbers (class and position). In order to calculate this, there are two ways.

The first one is to split the Streams browser into smaller ones depending on their class. The logic of finding for example the lower class Streams connected to each one of the third class Streams is simple: we ask from the system to find all the first class Streams that 'intersect' with each second class Stream and store the results in the second class browser (either by retrieving Streams from the table that holds the first class Streams, or by setting to the SQL the 'class=1' and retrieving from the global browser). Then we do the same for the second and third Stream classes and store the results into the third class browser. The SQL statement is similar to this :

**SQL clause :**  
 Select Riv2.Basin\_No, Sum(ObjectLen(Riv1.obj, "km")), Count(\*) from Riv2, Riv1 where Riv2.obj Intersects Riv1.obj group by Riv2.Basin\_No order by Riv2.Basin\_No into Selection  
 Browse \* From Selection

Having the relations between the Streams, we can easily ask for the total number of Streams related to a certain Stream, or globally for all the Streams separately of each class. The area of each basin is already calculated from a previous section. Applying the equation 5, we get a number for each basin, and then, using the GIS system, we define categories so that each category includes almost equal count of basins. Then we set a color for each range and we result in the color map of figure 5. The statistical numbers are shown in the next table:

Class	$\bar{F}$	$F_{\max}$		$F_{\min}$	
	Value	No	Value	No	Value
1	26,25	294	330,21	351	1,71
2	22,08	159	100,79	101	3,42
3	15,16	22	51,42	2	4,55
4	12,19	8	20,88	1	6,29
5	10,87	1	12,65	2	9,09
6	10,34	1	10,34	1	10,34

### Drainage Density Calculation

The drainage density indicates the total length of the Stream branches included in a basin, divided by the area of the basin. Equation 6 is similar to equation 5 except that

$$D_u = \frac{\sum L_u}{A_u} \quad (\text{equation 6})$$

instead of counting number  $N_u$  we use quantitative lengths  $L_u$ . The calculations are quite easy, as we already know the relations between the Stream branches and the areas from the frequency section.

With an SQL statement like the one used for the frequencies, we come to a new column that holds the accumulating lengths for each basin and then we divide by the area. The results are shown in the following table:

Class	$\bar{D}$	$D_{\max}$		$D_{\min}$	
	Value	No	Value	No	Value
1	4,40	294	18,98	387	0,59
2	4,50	136	8,16	23	1,81
3	4,15	22	6,71	5	2,27
4	3,85	14	5,02	1	2,88
5	4,40	1	4,15	2	3,42
6	3,65	1	3,65	1	3,65

As we previously did, we use the GIS system to arrange the basins into categories of equal ranges, and to apply a color for each category. The resulting map is in figure 6.

### Conclusions

The needed time was significantly less than performing the calculations manually. The possibility of calculation errors was eliminated because the computer calculated globally all the numbers and almost automatically designed the color thematic maps. In manual work on the other hand, the use of arithmetic calculators and the transfer of thousands of numbers from one column to the other, increase the possible calculation errors.

As far as the accuracy is concerned when measuring lines or length differences smaller than 50 m, equivalent to 1mm on a 1:50.000 map, results practically to the entire loss of data, due to the instrument's tolerance. As we can understand a small stream, for example a 20 m stream, will be practically ignored with a manual

measuring, while GIS can achieve measurement accuracies of 0,1mm or less, depending on the accuracy of the original source map that is coming from.

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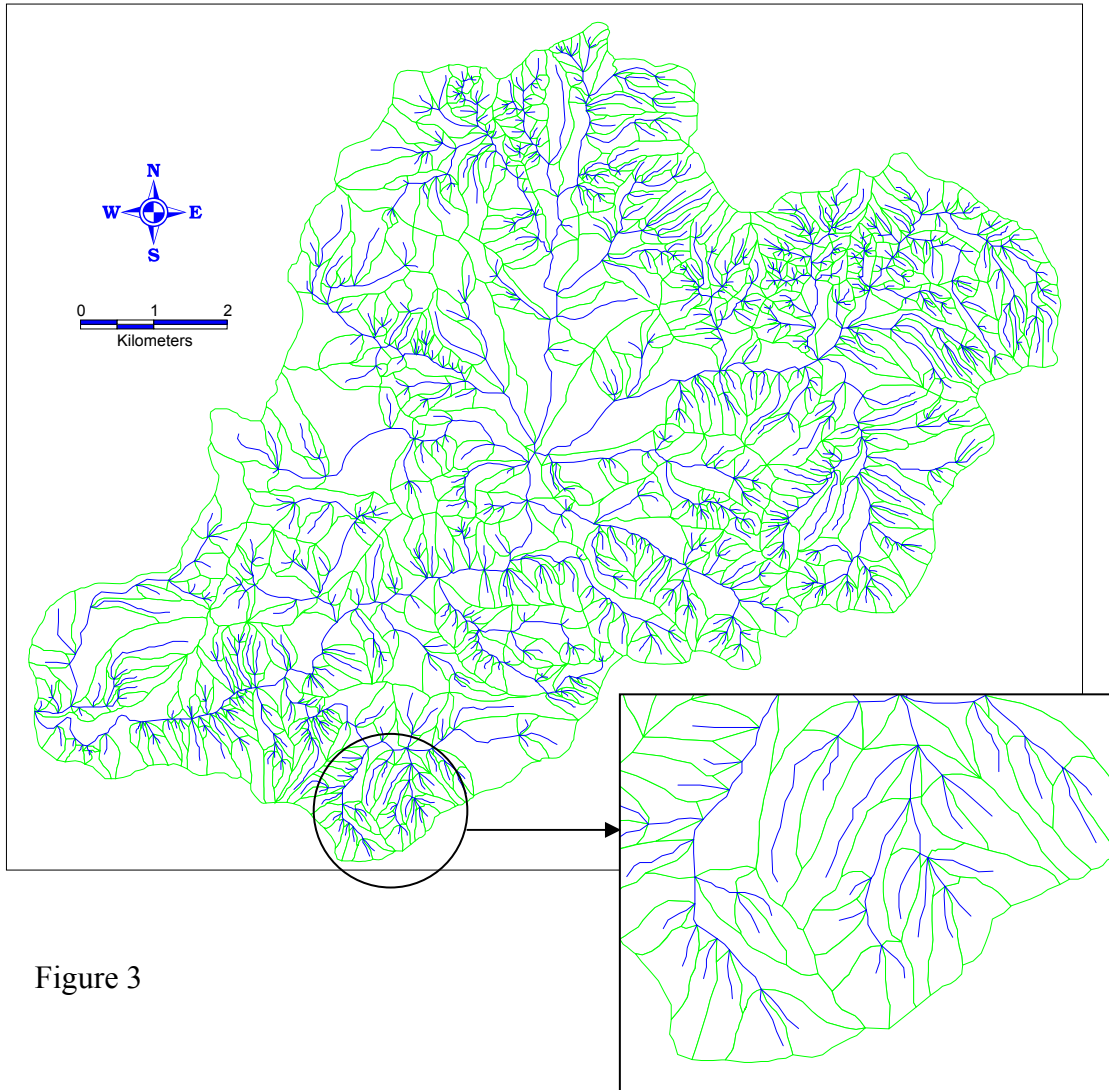


Figure 3

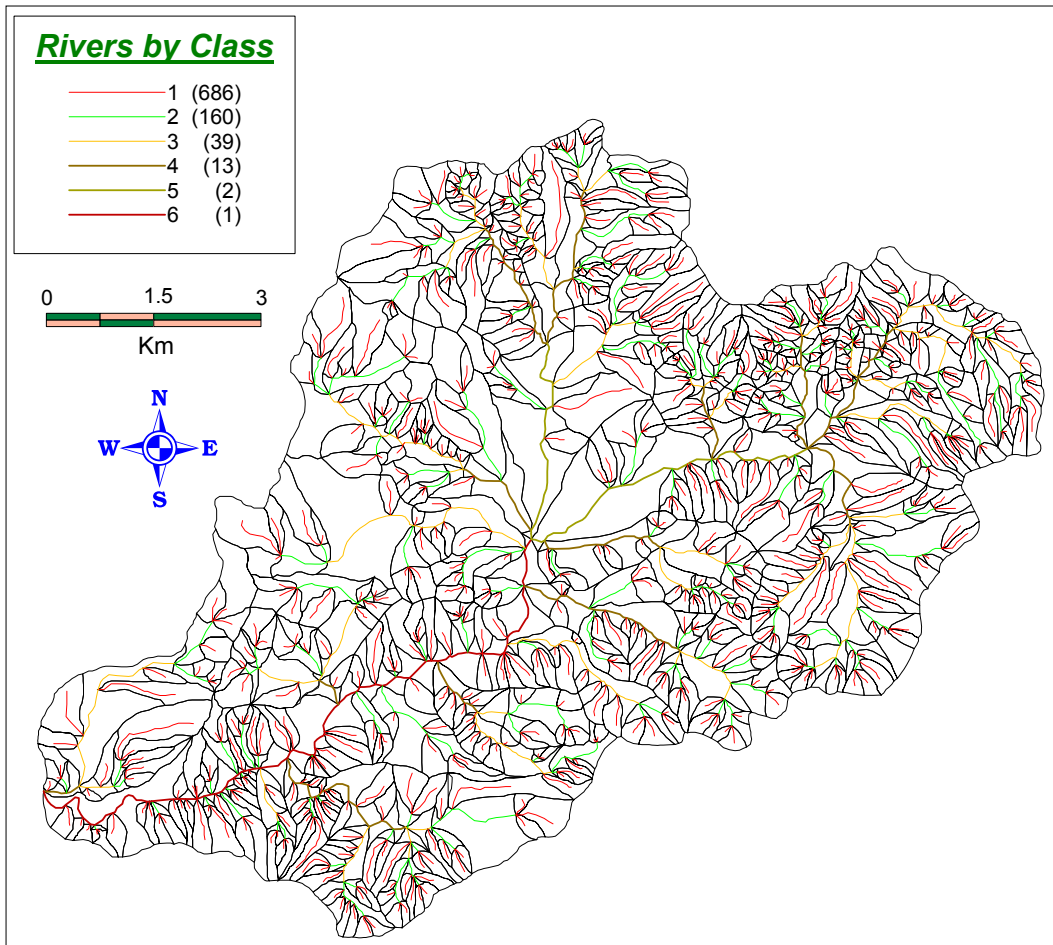


Figure 4



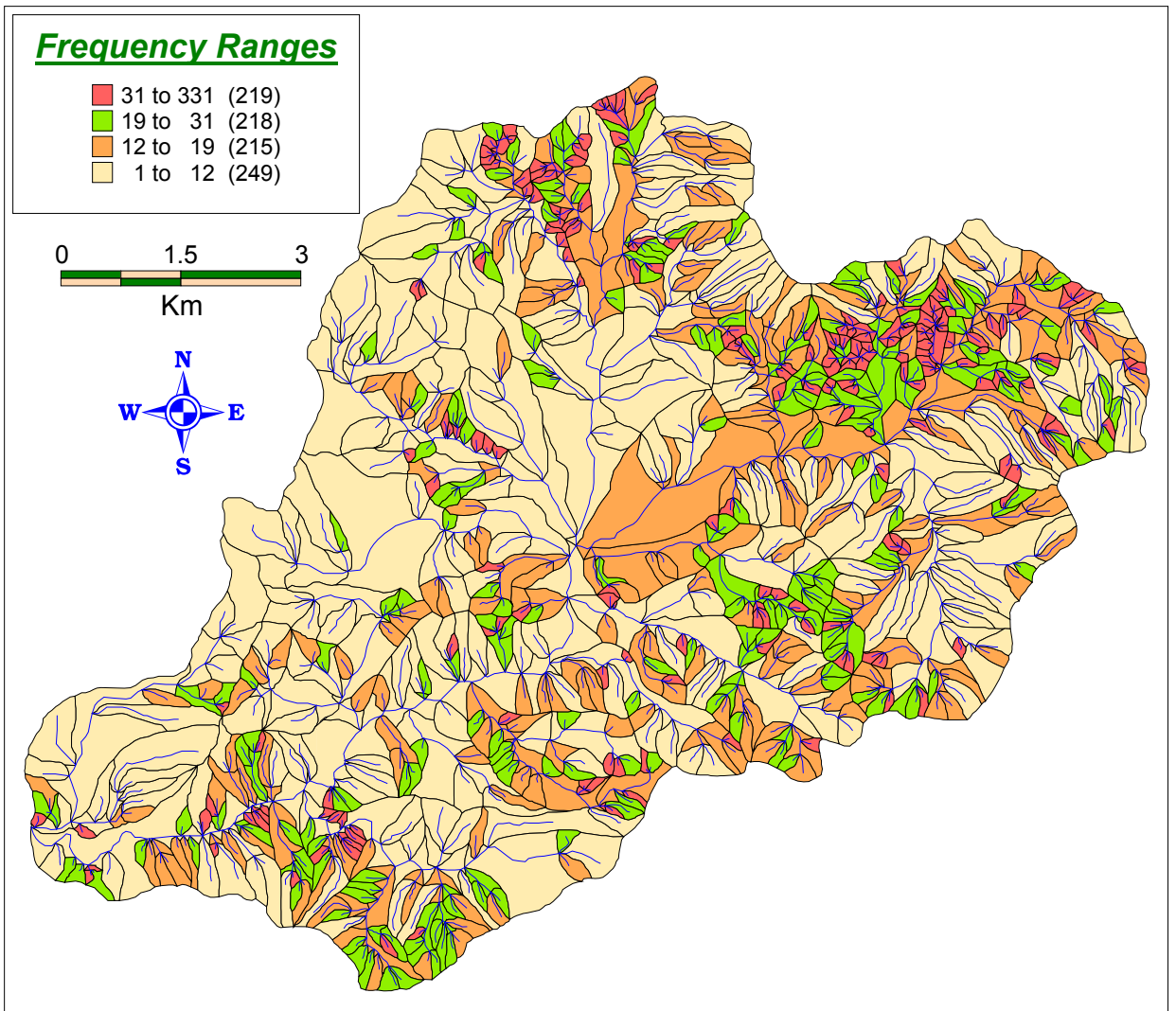


Figure 5

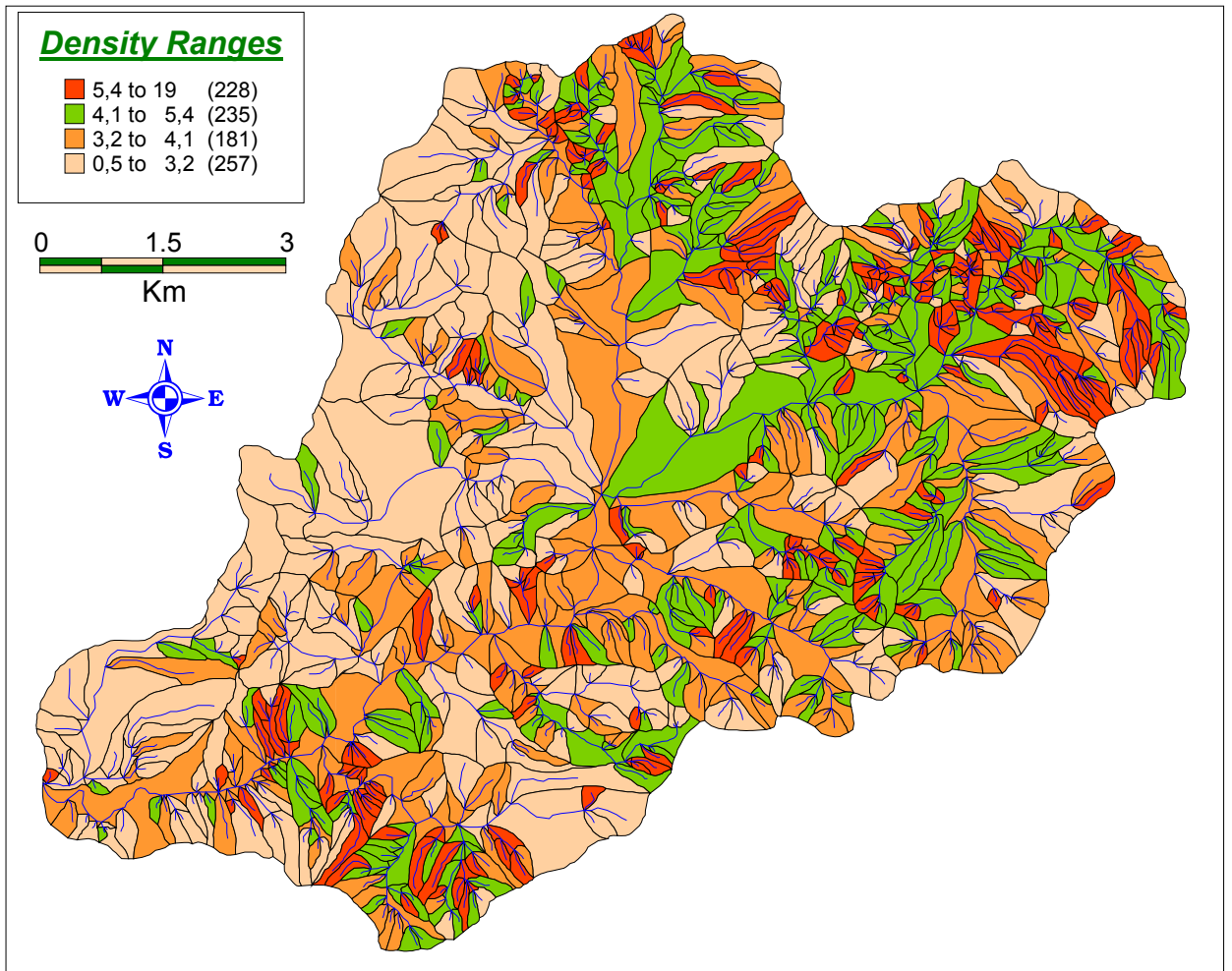


Figure 6