The derivation of the Potential Drainage Density Index (PDD)

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This paper focuses only on the technical details of the usage and creation of PDD. More details on the theory can be found in the chapter “The use of digital elevation data and Potential Drainage Density for regional soil characterization” by E. Dobos, E. Micheli and M. F. Baumgardner.

The Potential Drainage Density index, abbreviated as PDD, can be used for geomorphologic, pedologic and geologic characterisation of the landscape.

PDD is a measure of landscape dissection. The degree of surface dissection is determined by the surface runoff and the permeability of the soils and of the underlying rock strata. The less the water infiltrates into the soil, the higher is the water runoff on the surface, causing erosion and dissecting the land surface. Thus, the surface runoff is inversely related to permeability. A sandy parent material absorbs the majority of the surface water income, so there is basically no, or only limited runoff. A clayey parent material produces the most dissected surface, due to the very limited permeability and high surface runoff and erosion. Therefore, the landscape dissection is an indirect indicator of the soils and bedrocks.

Dissection is difficult to measure. A potential approach to characterize the degree of landscape dissection is to measure the total lengths of valleys or drainage lines. Drainage density (DD) is the total length of the permanent and seasonal streams and rivers divided by a unit size of area (A).

\[
DD = \frac{\sum_{i=1}^{n} L}{A}
\]
Where “L” is the length and “n” is the number of rivers. Unfortunately, real drainage density is also difficult to measure, because it requires good topographic maps in an appropriate scale. PDD is a terrain attribute, which can be derived from Digital Elevation Models (DEM). The word “Potential” was added to the name ‘Drainage Density’ to emphasize the difference between the actual drainage density as could be measured in the field and the DEM-derived one. The study area for demonstrating the procedure is shown on Figure 1.

In practice, PDD is used to delineate ridges, backslopes and valley bottoms on high relief areas, i.e. hilly and mountainous regions (Figure 2). Low PDD values represent local heights, elevated areas, ridge tops. Intermediate values represent backslopes, with higher values for the steeper sloping and lower for the more gently sloping areas. High PDD values refer to low-lying areas, depressions, valley bottoms and basins (Figure 3). On flat areas, where the relief is very low, PDD highlights depressions and local lows, where the surface drainage system forms a convergent flow channel pattern. Such a pattern often results in extremely high PDD values.
Figure 2. A classified PDD image of the study area. Brown colour represents ridges and local heights, greenish colour stands for backslopes and transitional areas, and blue for depressions and valley bottoms. Large and small boxes show the location of maps in Figure 4 and Figures 5-6, respectively.

Figure 3. A. Low, B. medium and C. high drainage densities within a circle-shape neighbourhood window. The dark, medium, and light grey colours represent areas with low, medium and high PDD values respectively. The windows represent a hilly region within the study area with the window size of 5 by 3.5 km.
Derivation of the PDD parameter

Most raster based Geographic Information System (GIS) software packages have built-in tools that can be used for the calculation of PDD. In this example, ArcInfo GRID commands and functions are used to describe the procedure. For their detailed descriptions, please refer to ArcInfo manuals [1].

Input DEM
Running the PDD procedure requires a depressionless or hydrologically corrected DEM. Sinks due to errors in the data have to be removed from the DEM. This can be done using the FILL command of the ArcInfo GRID module. However, it is often difficult to distinguish the sinks, which naturally occur in the data (e.g. sinkholes in karst regions) from those which are erroneous. Filling all sinks regardless of this characteristic may remove all natural depressions. In our data this has the effect of leveling up to the same elevation huge natural plain areas. By doing so, we loose all chances of differentiation on the plain areas, where few meters or even centimetres of elevation range represent a great variety of natural conditions. Instead of filling all sinks, it is therefore more appropriate to introduce a sink depth limit. Any sink deeper than the specified limit will be kept untouched. Only the sinks less deep than the threshold will be filled up to the level of their pour point. Our experience with the 90 m resolution Shuttle Radar Topographic Mission (SRTM) DEM data showed that a threshold value of 20 metre helps to remove the majority of the small sinks, while keeping the major elevation patterns untouched on the Pannonian plain. Of course this is in view of our objective to obtain a picture of the dissection of the area but not necessarily to obtain a hydrologically correct DEM.

Step 1. Flow direction

Within the ArcInfo GRID environment, the FLOWDIRECTION function can be used to create a grid/image of flow direction. The flow direction is the direction from each cell to its steepest downslope neighbour. The flow direction (Jenson and Domingue, 1988) is based on the highest drop value calculated for each of the eight neighbouring pixels as:

\[
drop = \frac{\text{change in elevation value}}{\text{cell centers distance}} \times 100
\]

If the descent to all adjacent cells is the same, the neighbourhood is enlarged until the steepest descent is found.

Step 2. Flow accumulation / Upslope contributing area / Catchment area

Based on the flow direction grid, the size of the contributing area to each grid cell can be calculated with the FLOWACCUMULATION function. The output grid represents the catchment area size of each grid cell expressed as cell counts.
Step 3. Drainage network

Applying a threshold value to the flow accumulation grid can create a stream network. All cells, which have a contributing area higher than a certain threshold value, are assigned a value of 1, representing the drainage path. All other cells, which have a flow accumulation value below the threshold are assigned “nodata” and become background cells (Figure 4).

The threshold value is set by the user. There is no certain quantitative rule to define it. For a 100 meter resolution DEM a threshold value of 100 cells (1 km² area) has been found to provide a realistic density of drainage lines characterizing well the real landscape. As the resolution becomes coarser, the representation of topography gets less detailed, while the area represented by one pixel is increased. Keeping the original minimum size of the upslope drainage area would increase the drainage density unrealistically, thus the minimum upslope drainage area has to be increased as well. We found that taking the 100-meters pixel size as a basic case, the incremental rate in pixel size can be used as a multiplication factor for the upslope drainage area size. For example, as we move from 100 to 500-meters pixel size, the size of the upslope drainage area should be increased from 1 to 5 square kilometres, while the number of threshold pixels is decreased from 100 to 20 accordingly.

Figure 4. The drainage network derived from the 90 m resolution SRTM. For location see Figure 2.

From figure 4 some artefacts can be identified in the form of parallel, densely located drainage lines. This pattern occurs on areas where the original image had sinks that were filled up and levelled to large flat areas by the FILL command of ArcInfo GRID to make the
drainage network creation possible. On such flat areas, the program has difficulties with identifying the flow direction, because the descent to all adjacent cells is the same. In this case the neighbourhood is enlarged until the steepest descent is found. This procedure results in straight parallel lines running towards the pour points, which often produces a very high drainage density. Although it is an artefact, the interpretation is still valid and useful because this pattern highlights depressions within the landscape, which are generally representative of valley bottoms.

Step 4. Calculation of Potential Drainage Density (PDD)

The final step of creating the PDD image is to run the FOCALSUM function on the drainage network layer. The function sums up the cell values that fall within a predefined shaped and sized neighbourhood and assigns the sum to the centre cell. In our case, summing is equivalent to a simple count of the cells representing drainage lines as they all have a value of 1. The neighbourhood window then moves through the entire image and calculates the PDD value for every pixel.

For computing the PDD, a circle shape neighbourhood is chosen for which a radius expressed as a number of cells has to be specified. The radius size can vary based on the need of the user. However, in order to produce a full, continuous coverage of the area, one should make sure that the size of the radius is big enough for the function to always ‘catch’ at least one drainage cell so as to avoid having empty neighbourhoods. A large radius tends to generalize the image, while a smaller one helps to maintain the physiographic patterns. Moreover, enlarging the neighbourhood increases computing time, which is a problem when a large DEM is used. As an example the image of figure 5 was produced from a 90 m SRTM DEM, with a drainage threshold of 100 cells and a FOCALSUM radius of 15 cells. Figure 6 presents the same image after classifying it into three classes.

The PDD is an artificial image with cells having a value referring to the length of drainage ways in a specified neighbourhood of each cell. In this sense, the ’drainage density’ image differs from the ‘drainage network’ image. It has to be clarified here that the term "drainage density" is not identical to the one used by geographers and geomorphologists. It is not based on the real drainage network, it is only derived from a digital terrain model. Therefore it does not take into consideration the loss of surface water due to infiltration into the soil. The potential drainage density is always higher or equal to the real drainage density of an area.
Figure 5. PDD image derived from a 90 m resolution SRTM DEM. For location see Figure 2.

Figure 6. Classified PDD. Light colour refers to depressions and valley bottoms, intermediate colour to backslopes, and dark colour to ridges and local heights. For location see Figure 2.
An Arc/Info AML file to derive a PDD layer from a filled DEM

(see short documentation at end of AML)
(AML can also be downloaded from http://support.esri.com/ > Downloads > ArcScripts)

/* PDD.AML
/* Joel Daroussin - JRC Ispra - 07/10/2004
/* Updated 20/12/2004: documentation.
/* AML built under ArcInfo 9.0 on PC.

/* --------------------------------------------------------------------------
/* Init:

&echo &off save_echo
&args InAltGrid CatchmentAreaKm2 PddRadiusKm OutPddGrid rest:rest
&severity &error &routine error
&sv save_messages = [show &messages]
&messages &on

/* Debugging tool:
&sv debug off /* set to on or off.
&echo &%debug%
&if %debug% = on &then &messages &on

/* *--------------------------------------------------------------------------
/* Arguments control:
&if [show program] <> GRID &then &do
 &type This AML works only from Grid.
 &call error
 &end

&if [null %OutPddGrid%] or not [null %rest%] &then &call usage

&if not [exists %InAltGrid% -grid] &then &do
 &type Grid %InAltGrid% not found.
 &call error
 &end
 &describe %InAltGrid%
 &if %prj$units% <> METERS &then &do
 &type This AML works only on projected grids with units METERS.
 &call error
 &end

&if [type %CatchmentAreaKm2%] > 0 &then &call usage
&if [type %PddRadiusKm%] > 0 &then &call usage

&if [exists %OutPddGrid% -file] or [exists %OutPddGrid% -directory] &then &do
&call error
&end
&if [exists %OutPddGrid% -file] or [exists %OutPddGrid% -directory] &then &do
&call error
&end
&if [exists pddtmp1 -file] or [exists pddtmp1 -directory] &then &do
&call error
&end
&if [exists pddtmp2 -file] or [exists pddtmp2 -directory] &then &do
&call error
&end

/* --------------------------------------------------------------------------*/
/* Main:*/
/* Convert catchment area threshold from km to number of cells:*/
&sv CatchmentAreaCells = [truncate [calc ( ( %CatchmentAreaKm2% * 1000 ) ** 2 ) / ( %grd$dx% * %grd$dx% ) + .5]]
&type Catchment area threshold converted from %CatchmentAreaKm2% km2 to %CatchmentAreaCells% cells

/* Create drainage network layer:*/
pddtmp1 = con(flowaccumulation(flowdirection(%InAltGrid%)) >= %CatchmentAreaCells%, 1, 0)

/* Convert radius of the PDD moving circle from km to number of cells:*/
&sv PddRadiusCells = [truncate [calc %PddRadiusKm% / %grd$dx% + .5]]
&type Radius of the PDD moving circle converted from %PddRadiusKm% km to %PddRadiusCells% cells

/* Create PDD layer (as number of drainage cells within the %PddRadiusCells% moving circle):*/
&type Computing PDD...
%OutPddGrid% = focalsum(pddtmp1, circle, %PddRadiusCells%) &messages &off
kill pddtmp1 &messages &on

/* Convert PDD from number of cells to km/km2:*/
&type Computing PDD in km/km2...
 /** PDD holds the number of drainage cells within the %PddRadiusKm% circle. /** The circle is (Pi * %PddRadiusKm% ** 2) km2:
&sv area = 3.141592 * %PddRadiusKm% ** 2
/** Each cell represents a drainage length of either the grid's resolution
/** or its diagonal. Let's set it to an average of the two:
&describe %OutPddGrid%
&sv length = ( %grd$dx% + %grd$dx% * 2 ** .5 ) / 2 / 1000
/** Each PDD value thus represents:
%OutPddGrid%km = %OutPddGrid% * %length% / %area% /* km/km2

/* End of main:

&type Resulting grids:
&type %OutPddGrid%: PDD expressed as cell counts
&type %OutPddGrid%km: PDD expressed as km/km2
&call reset
&return

/* Subroutines:

/* General error handling routine:
&routine error
&severity &error &ignore
&type Abnormal termination of program [upcase %aml$file%].□
&call reset
&return &error

/* Usage:
&routine usage
&type Syntax error.□
&type Usage: &RUN PDD <input elevation grid> <drainage area threshold (km2)>
&type <PDD moving circle radius (km)> <output PDD grids prefix>
&type More help available from pdd.txt and pdd.doc.
&call reset
&return &error

/* Restore environment:
&routine reset
&messaging %save_messages%
&echo %save_echo%
&return

/* COMPUTES THE POTENTIAL DRAINAGE DENSITY (PDD) INDEX FROM AN
ELEVATION GRID.

Usage: &RUN PDD <input elevation grid> <drainage area threshold (km2)>
        <PDD moving circle radius (km)> <output PDD grids prefix>
Arguments:

<input elevation grid> - Name of the elevation grid input to the procedure. Grid must be projected with units METERS.

<drainage area threshold (km²)> - Threshold value in km² used to initiate delineation of the drainage network.

<PDD moving circle radius (km)> - Radius in km of the moving circle used to count drainage network pixels within the centre cell's neighbourhood.

<output PDD grids prefix> - Name of the output PDD grid. This first grid will hold counts of drainage network cells. A second grid named <output PDD grids prefix>km will be output to hold km of drainage network by km².

Notes:

For better results consider using a FILLed (hydrologically corrected) input elevation grid (see ArcInfo Grid command FILL for more information).

Computing length (km) of drainage network by km² is a simple unit conversion process neglecting diagonal versus horizontal (or vertical) lengths of drainage lines. The length used is averaged from the straight and the diagonal lengths of cells.

References


Referred web page