1.2 Drainage Density

The map of drainage density presents this morphometric parameter in a new way. Not only does it take into account the drainage network of flowing surface waters (rivers, ditches, channels); it also takes into account standing waters (lakes, ponds, reservoirs – these are all referred to as “lakes” in the following text). Drainage density, as it is used here, is the sum of the conventional *river density* (the sum of river and channel lengths per unit area) and the “lake density”; the lake density is calculated here as the sum of lake diameters per unit area, in contrast to its usual definition as the sum of lake areas per unit area (cf. Map 3.3 “Standing Waters”). Both densities are expressed in km/km^2. The adding together of the two densities tends to reduce the number of regions in which there appears to be only a low river density although there is in fact a high density of surface waters (flowing waters and standing waters together). This procedure is justified by the hypothesis that lakes behave in a hydrologically similar way as the part of a river network does: both water types have drainage and storage functions, although for lakes the storage function is paramount.

It is the river density that contributes most to the drainage density shown on the map. River density provides an integrated and regionally representative measure of runoff generation, and it determines the water and material budget of a region. It can be seen as a quantitative river network descriptor, one that describes features such as the mean distance between a network’s surface waters, the way in which a network’s land and surface water areas interfinger, and, more generally, the way in which groundwater and surface water interfinger. Drainage density affects runoff generation and runoff concentration, and it is partly responsible for the different reactions that drainage basins have to precipitation events.

River density and hydrological research

The river density, when taken as a characteristic measure of the drainage of an area, has long held a prominent position in hydrological and geomorphological research. The factors leading to the formation of drainage networks of different densities are complex, and are not fully understood. The factors that affect river density may be totally different from those that affect lake density.

The magnitude of the river density D_R in the moderately humid climate in Germany is mainly controlled by precipitation and subsurface conditions. Other factors also influence the magnitude of the river density and, partially at least, also the lake density: these factors include relief, depth to groundwater table, density of vegetation cover, land use, soil properties, and anthropogenic effects such as the use of ditches or channels for drainage or irrigation. The ways in which the individual factors influence river density is shown qualitatively in Figure 1. The influence of the different factors is at a wide range of map scales, from small-scale (global) to large-scale (regional to local). The influence of each of these factors is time-dependent (because the Earth’s surface and drainage network are continually evolving), and the relative importance of the individual factors is different at different geological times.

Investigations of river density carried out so far have been almost exclusively in small drainage areas (map-scale of 1 : 25,000 or more). Therefore the investigations on which this map is based started with spot checks to examine the changing value of river density over different map-scales – the larger the map-scale, the higher the river density that is found. When looking at very small areas, it is always necessary to take short-term dynamics into account. Dry valleys and small channels that carry water only after rain both have to be taken into consideration. This is particularly important when investigating peak flows, as flow concentration is dependent on river density.

Ways of determining river density

In order to determine river density, there must be suitable information on the water body network (digital line and area data) available, which cover the area of investigation and are comparable in quality. Line data of rivers should preferably be derived from large-scale maps that have only small errors and losses due to generalisation. When digital elevation models are used, it is valley density that is calculated, which often differs from river density. Differences between valley density and river density that are due neither to the map-scale used nor to the calculation method used are an indication of different paleoclimatic conditions in the investigation area (e.g. dry valleys).
River density is not a spatial continuum; instead it changes in a scale-dependent way, sometimes abruptly, depending on the properties of the particular area concerned. Areal units used for calculating river density can be chosen in two ways: they can be polygons that are as far as possible homogeneous, or they can be grids with cells of a specified size. It is preferable to use ‘natural areal units’ – ones that have similar properties (soil properties, geology, geomorphology, land use, etc.). Such units have been defined in Germany, but their resolution is too variable to allow them to be used to as the basis for detailed, areally comprehensive calculation of river density.

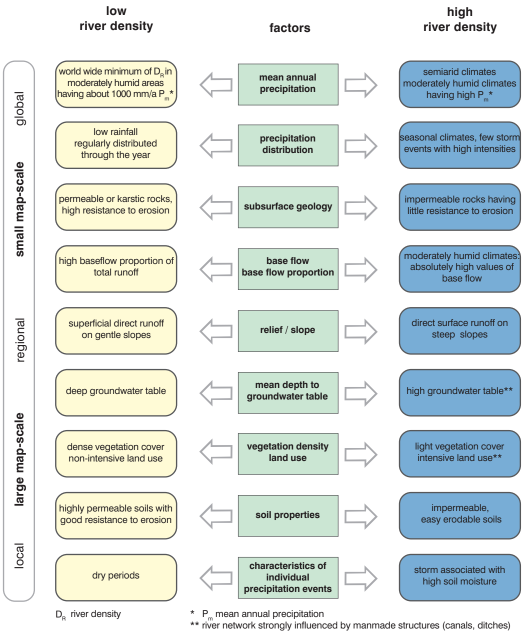

Fig. 1 Factors influencing river density in relation to scale of view

An alternative, grid-based method of computing the river density uses the sum of river lengths per unit area as a direct density measure. This method has been tested here and rejected, because for small grid cell sizes (< 5 km) the resulting density distribution becomes random and spatially incoherent. If this distribution is subsequently smoothed, or if a coarser cell size is used, then regional patterns are obscured and positional errors due to grid geometry are introduced. There seems to be no satisfactory compromise between high spatial resolution and adequate smoothing, a compromise that shows both regional differences and their wider context.

Map Structures

The method used to calculate the river density (*Line Density* Method, Silverman 1986) counts the sum of river line lengths in a user-definable circular area around a central grid cell and then calculates the line length per unit area (see key to Map 1.2). The method produces a certain smoothing, which shows regional characteristics at the same time as it shows relatively sharp changes between areas having different properties. A circle area of 75 km^2 (corresponding to a circle radius of approximately 4887 m) has been found to be most suited to mapping river density at the map scale chosen here.
The input data used for determining river lengths are lines derived by automatic vectorisation and subsequent interactive editing of DLM 200/V data; these data are available as scans from river network films of the 1 : 200,000 topographical map series. (A river network obtained in this way has small gaps and is systematically about 4 % shorter than a complete river network obtained by interactive vectorisation using line-following methods; however, far less work is involved in obtaining it.) Double lines for larger rivers are not counted, because drainage density does not take river widths into account. Canals are treated as natural flowing waters, because there is no hydrologically justifiable way of separating them in individual cases.

Lake diameters are obtained from the 1 : 1,000,000 digital landscape model ATKIS DLM 1000; this database is vectorised and contains topographical information from the 1 : 500,000 international topographical map series (Series 1404, World). The database contains about 8500 lakes within Germany, with surface areas ranging down to under 0.1 km^2. The perimeter length P_L of each lake is divided by π to give that lake’s nominal diameter d_L ($d_L = P_L / \pi$) – this diameter is the correct one if the lake is circular – and this diameter is taken to be equivalent to river line length for computing drainage density. The lake density obtained in this way is added to the previously obtained river density. This procedure does not, strictly speaking, give an ‘equivalent river density’ for lakes, but it treats lakes rather as meandering rivers.

The colours used in Map 1.2 show classes of equal drainage density. The drainage density is dominated by the river density component. The mean river density is approximately 0.77 km/km^2 for Germany as a whole. The lake density component increases this mean value by only 0.015. The effects of lakes on drainage density are only regionally noticeable.

Inferences about subsurface permeability and about runoff relationships can be drawn by comparing river densities in areas of similar precipitation conditions. A low river density may indicate high permeability, deep seepage and little surface runoff (e.g. karstic terrain). River density is therefore a good way of differentiating regions that have different drainage characteristics.

The areas of high river density on the map are clearly seen to be (a) in areas of high precipitation and relatively impermeable subsurface conditions, and (b) in low-relief areas along the large rivers, where the groundwater table is high. Very high values of river density (up to about 2 km/km^2) usually indicate Man’s influence; they are predominantly on the coastal plains and along the estuaries of the larger rivers, the Elbe, the Weser and the Ems. In those areas there is a very dense network of drainage channels and ditches, which were evidently not removed when the map was generalised to the 1 : 200 000 map scale. Individual similar structures, but ones that are only of regional significance, are occasionally found upstream in the valleys of the rivers mentioned.

High river densities (> 1.3 km/km^2) are found in wetlands along large rivers and in the region to the north of the Alps. Moderately high river densities (values around > 1 km/km^2) are found in mountainous areas such as the Harz and the Schwarzwald (Black Forest). At higher elevations in those areas, it is high precipitation rates and low subsurface permeabilities that are responsible for high values of river density; in the actual vicinity of the rivers, however, it is high groundwater tables and persistent discharge from porous aquifers that are responsible.

The river densities in limestone and sandy areas are very low: they fall to almost 0 km/km^2. In karstic terrains such as the Schwäbische Alb and the Fränkische Alb (Swabian Alb and Franconian Alb, respectively), most of the precipitation seeps underground. Seepage into the subsurface is also dominant in situations in which the subsurface is permeable and the distance from the surface to the groundwater table is high; this explains the low river density values of under 0.4 km/km^2 that are found, for example, in the area around Köln (Cologne) and in the sandy areas of north-eastern Germany. Low mean precipitation in the eastern states of Germany is part of the reason for the low river density there; in a few, rain-shadowed areas – such as to the east and the north-east of the Harz Mountains – low precipitation may indeed be the prime reason for low river density.

The numerous lakes found particularly in formerly glaciated areas contribute to the drainage density there. These lakes are formed by glacial erosion and by the development of depressions in regions of moraines. Seepage in the subsurface is impeded because pore-networks there are choked with fine-grained material. These conditions are found in the lake territory of Mecklenburg-Vorpommern and Brandenburg, where there is a below-average river density of about 0.4 km/km^2 and a similarly valued lake density. In the south German Alpine foreland, there are above-average river densities and relatively high lake densities. Regionally restricted areas of high lake density, e.g. in the Mittelfränkisches Becken (Middle Franconian Basin) or in the ‘pond area’ of Oberlausitz, are due to the building of artificial ponds in past times. A detailed picture of the distribution of lakes in Germany is given in Map 3.3 “Standing Waters”.

Practical Information

The results given here are supported by investigations using different sources of line length and areal data and by spot checks of the scale dependence of river density carried out using various topographical map series. The results are also consistent with calculations of river density carried out using ‘Natural Areal Units’ (LANIS, German Federal Office for Nature Conservation, Bundesamt für Naturschutz), these units having an average size of about 700 km^2. The map shown here is much more detailed, however. This consistency confirms that the factors used to delineate different natural areal units (predominantly relief, geology, amount of precipitation) are largely identical to the relevant factors that influence the development of drainage networks. Nevertheless, the natural areal units have the disadvantage – partly due to their size – that they lump together river densities over areas that are heterogeneous.

Even though it is only a synoptic map, Map 1.2 has some notable advantages.

- The use of official topographic data to obtain line length data has the advantage of giving results that are unambiguous and that have clear map-scale dependencies. In contrast, the use of digital elevation models to obtain valley lengths is very strongly map-scale- and method-dependent and at the same time can give valley densities that differ greatly from the real river density.
- Drainage density treats both standing waters and flowing waters adequately, even though it is still not really an ‘Equivalent River Density’ parameter.
- There are strong correlations (r > 0.93) between density values calculated using the vectorized DLM 200/V data and values obtained using analogous larger-scale maps (topographical map series 1 : 25,000, 1 : 50,000 and 1 : 100,000, and Natural Areal Units). The correlation between density values obtained using the DLM 1000 and the values from these other maps is weaker (r ≈ 0.7), especially in regions with short valleys and intensively-branched drainage networks; in these regions the drainage density is anomalously low.

The change in river density that is found when changing from small-scale to large-scale maps cannot be expressed by constant conversion factors, because the density decrease differs in different types of areas. It is therefore not advisable to use values of river density from the map as the basis for modelling small-sized areas e.g. individual catchment areas or areas similar in size to those on which the map itself is based. However, for regional and wider-area investigations, this areally comprehensive map is a suitable basis for planning and modelling in applied hydrology and for hydrological research.