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# Impact of slope aspect on hydrological rainfall and on the magnitude of rill erosion in Belgium and northern France

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## Abstract

The impact of slope aspect on hydrological rainfall and on the magnitude of rill erosion has rarely been studied. The dominant wind direction in Belgium and the northern of France is the southwest, which brings large amounts of rain with it. We investigated whether this leads to greater rates of rill erosion on the southwestern slopes, due to the greater amount of hydrological precipitation on these slopes. The study was executed on six barren conical spoil heaps, which are excellent study objects to bring the slope aspect in relation with rill erosion. Three indicators for rill erosion (volume of rills, drainage density and mean distance of the head cut of the five uppermost rills till the top of the spoil heap) were associated with four explanatory factors (slope gradient, vegetation density, rock fragment cover and slope aspect). The amount of hydrological rainfall is the greatest on the western and southwestern slopes. As a result, the largest volume of rills was measured on the slopes facing the southwest (96%), which indicates that there is a connection between the slope aspect and the magnitude of rill erosion. On the northeastern (32%) and eastern (36%) slopes the volume of rills is lower due to the effect of rain shadow. The other explanatory factors showed little influence on the magnitude of rill erosion, as the spoil heaps were selected to be similar in as many parameters as possible.

**Key words:** rill erosion, spoil heap, hydrological rainfall, slope aspect, northwest Europe

## 1. Introduction

Many studies have been conducted with a view to rill erosion in Belgium and the north of France on cultivated catchments (Govers, 1991; Auzet *et al*., 1993; Vandaele and Poesen, 1995; Cerdan *et* al., 2002). Despite the knowledge that slope aspect impacts hydrological rainfall and soil erosion (Hurni, 1988; Ragab *et al*., 2003), these effects have been rarely quantified for rill erosion (Nyssen and Vermeersch, 2010).

Rill erosion depends on various factors: impact of raindrops and soil surface crusting (Morin *et al.*, 1981), rain intensity (Römkens *et al.*, 2001), slope aspect (Nyssen and Vermeersch, 2010), vegetation (Moreno-de las Heras *et al.*, 2008), stoniness (Abrahams & Parsons, 1990; Moldenhauer and Kemper, 1969) and slope gradient (Römkens *et al.*, 2001).

The amount of rill erosion strongly depends on the amount of hydrological rainfall, the rainfall as it would be measured by a tilted rain gauge with its orifice parallel to the soil surface, per unit of horizontally projected orifice area (Blocken *et al*., 2006). The meteorological rainfall is the amount of rainfall as measured by a conventional rain gauge with a horizontal orifice, per unit orifice area (Blocken *et al*., 2006). The amount of hydrological rainfall depends on various factors: geometry of the ground surface, location in the topography, wind velocity, slope aspect, rain intensity and the size of the raindrops (Blocken *et al*., 2006). The dominant wind direction in Belgium and the north of France is southwest, which brings rain from the Atlantic. It can be expected that the slopes facing the southwest will have a greater volume of rills due to the larger amount of hydrological rainfall.

The study objects for this research are spoil heaps. They are very useful because they are conical landforms, therefore all slope aspects are available. They have a relatively homogenous land cover and are also often higher than the surrounding buildings and vegetation, so that the weather conditions have a direct influence on them. They are made up of loosely compacted material, making them susceptible to erosion (Nyssen and Vermeersch, 2010). Also the slope gradients are similar.

The objectives of this study are (1) to calculate and map hydrological rainfall for high intensity rain events in Belgium, (2) to quantify rill erosion as a function of slope aspect and other explanatory factors, and (3) to link it up with hydrological rainfall distribution.

## 2. Materials and methods

### 2.1 Study area

Fieldwork was done on spoil heaps in Belgium and the north of France. They are witnesses of the coal industry that flourished in the 19th and 20th centuries in these regions. Spoil heaps are made up from different materials: sterile rock together with waste, such as wood from the mines, old iron and scoria. Scoria is a general term for waste derived from the steel industry. Today the spoil heaps are very apparent in the landscape, with in most cases a conical form (Figure 1). The waste was removed by rail with a wagon to the top of the spoil heap, where it was poured out. The largest blocks rolled down and piled at the foot of the spoil heap (Debehault, 1968). The rocks that make up a spoil heap date back to the Westphalian and Namurian and consist mainly of psammite and coal remains. Until the 1960s coal was the main source of energy in Belgium and due to the exploitation there appeared many spoil heaps. Thanks to the coal mines there were many employment opportunities in these regions (Debehault, 1968), which attracted people and therefore new settlements arose near the spoil heaps.

After exploitation, the spoil heaps have been colonized by vegetation, growing from seeds that were brought in by avian and aeolian dispersion. This colonization occurred from the bottom to the top, causing that some peaks are still barren. Species with light seeds (birch, grasses, and spore plants) have been found to dominate, followed by those with heavier seeds (oak, hazel, beech, sycamore, and ash) (Debehault, 1968).

Spoil heaps are also characterized by steep slopes, with in this study an average slope gradient of 24°. Research on slope processes reported in literature includes sheet and rill erosion (Evans et al., 2000; Willgoose and Sharmeen, 2006; Hancock et al., 2008; Nyssen and Vermeersch, 2010) and the subsequent armouring (Willgoose and Sharmeen, 2006). A preliminary investigation of rill erosion on spoil heaps shows that it is related to slope aspect, to vegetation density, to grass cover, but particularly to tree cover. The impeding effect of shallow birch roots on rill erosion has been stressed (Nyssen and Vermeersch, 2010).

***Insert Figure 1 here***

### 2.2 Rain intensity and wind direction

The rain intensity and the wind direction are two key factors for rill erosion. A higher intensity of rainfall will lead to more erosion. In the study area, wind coming from the west and southwest brings more rain than wind coming from the east. The data for these two variables with a temporal resolution of 1 hour was obtained from the Royal Meteorological Institute of Belgium. For the rain intensity, a distinction was made between two classes, after Poesen *et al*. (2003). Class 1 contains all the data with a rain intensity of 5 mm/h and higher. This class is considered to be highly erosive. Class 2 contains all the data with a rain intensity of 2 mm/h and higher and is considered to be moderately erosive. Class 2 and class 1 were together divided according to the seasons: winter (January, February and March), spring (April, Mai and June), summer (July, August and September) and autumn (October, November and December). Class 1 alone was not divided in seasons due the size of the dataset. Data with a rain intensity below 2 mm/h was not included in this study, because these rain intensities have little effect on erosion.

The rain intensity values were obtained from four meteorological stations in Belgium (Figure 2): Melle, Retie, Zaventem and Saint-Hubert. The wind data was often incomplete in the four meteorological stations. This data could be supplemented with data from neighboring meteorological stations. To determine the dominant wind direction, it was calculated how many times each wind direction occurs in the data and polar diagrams per season were created.

To determine the hydrological rainfall, there are various factors of importance: the total depth of the precipitation, the mean wind velocity, the rain inclination and the dominant wind direction. The hydrological rainfall is given by the following equation (Fourcade, 1942):

$$P^* = P\,(1 + \mathrm{tg}\alpha\ \mathrm{tg}\beta\ \cos(z\alpha - z\beta)) \tag{1}$$

where: $P^*$ and $P$ are the hydrological rainfall and the reference rainfall at the point (mm); $\alpha$ is the local inclination of the ground surface at that point relative to the horizontal (°); $\beta$ is the inclination of the rainfall relative to the vertical (°); $z\alpha$ is the aspect of the ground surface at that point (°); and $z\beta$ is the direction from which the rain is coming (°).

### 2.3 Selection of studied spoil heaps

Among all the spoil heaps in the study area, spoil heaps were considered eligible for this study if having a conical shape, a top with almost no vegetation and slopes that are similar in as many parameters as possible. These selection conditions yielded a virtual selection of fifteen spoil heaps in Google Earth. The fifteen spoil heaps were examined on the field, which led to a selection of six usable spoil heaps, with two spoil heaps situated in Belgium and four in the north of France (Figure 2, Table 1). The spoil heaps in Belgium are located in Alu, west of Charleroi and in Fléron (Terril Hasard), east of Liège. In the north of France, two spoil heaps are located in Loos-en-Gohelle, north of Lens and two in Houdain, west of Lens. The six spoil heaps belong to the same coal basin, that runs from Nord-Pas-de-Calais in the west through the Borinage and Charleroi till Liège in the east.

The average height of the spoil heaps is 55 m and they cover an average area of 16 ha. On two of the six spoil heaps, isolated self-combustion (sensu Bell, 1996) is still present. The beginning of the deposition took place at the end of the 19th century and the beginning of the 20th century. The end of the deposition was at the end of the 20th century.

***Insert Figure 2 here***

***Insert Table 1 here***

### 2.4 Field measurements of rill erosion and explanatory factors

Fieldwork took place between September 2012 and April 2013. The top of the six spoil heaps was subdivided in eight sectors. Each sector corresponds to a main slope aspect and has a projected length of 30 m. A distinction was made between usable sectors and unusable sectors. An unusable sector is a sector which cannot be measured as a result of human and natural activities (example: road, landslide), which could lead to distortions. Besides the slope aspect, we also considered three additional explanatory factors: slope gradient, vegetation density and rock fragment cover. The slope gradient per sector was measured in the field with a clinometer. The vegetation density was visually determined on high resolution Google Earth imagery. The relative vegetation density was determined in this research i.e. a percentage of the highest density among the eight sectors per spoil heap, in order to give the same importance to all studied spoil heaps. The rock fragment cover per sector was measured using systematic observations and calculated as (Nyssen et al., 2001):

$$Rfc(\%) = 100\ n_p/n_t \qquad (2)$$

where: Rfc(%) is the rock fragment cover; $n_p$ is the number of observations with a rock fragment present (minimum section 1 cm); and $n_t$ is the total number of observations.

To investigate the magnitude of rill erosion, three indicators were measured in all sectors: the volume of rills, the drainage density and the mean distance of the head cut of the five uppermost rills till the top of the spoil heap. For each spoil heap, every rill in every sector was measured separately. A tape measure and yardstick were used to measure the width and the depth of the rill. The number of measurements was dependent on the total length of the rill. In the most cases there were three measurements per rill. For the long rills, the number of measurements could go up to six and for the short rills up to two. The method used here provides a systematic exaggeration of the cross section of the rill, which did not cause a problem because the absolute volumes are not of great importance in the analysis. The rills were mapped in the field using a GPS. Subsequently it was possible to visualize the rills in ArcGis 9.3.1. and to measure the total volume of the rills per sector, the drainage density per sector and the mean distance of the head cut of the five uppermost rills till the top of the spoil heap.

For each spoil heap, a general map was created (Figure 3), showing the usable and unusable sectors, the location of the vegetation and the location of the rills. The rills were divided in three classes on the basis of the cross-section.

***Insert Figure 3***

The terril Hasard in Fléron showed, on the basis of the calculated rills, a different pattern with respect to the other spoil heaps. With the largest volume of rills on the slope facing the east and the smallest volume on the slope facing the southwest. The east facing slope on this spoil heap has a slope gradient of 37° as compared to an average gradient of 29° for the other sectors. The equilibrium slope, which is between 35° and 40° on spoil heaps (Debehault, 1968), is thereby exceeded. A threshold value has been exceeded, so that the expected link between the slope gradient and the volume rills no longer applies. The terril Hasard was considered as an outlier and not further used in the study.

## 3. Results

### 3.1 Wind direction per rain intensity class

As mentioned in 2.2, there are two classes for the rain intensity. Class 1 with all the rain intensities higher than 5 mm/h and class 2 with all rain intensities higher than 2 mm/h. The focus in this study is on class 1, because this class includes the rain intensities which will have the greatest impact on rill erosion. The dominant wind directions for the four meteorological stations were determined during the rains and are shown on the compass roses (Figure 4).

***Insert Figure 4***

This shows that the wind in Belgium, with rain intensities higher than 5 mm/h, lies in approximately in 47% of the cases between the main cardinal directions SSW and WSW.

### 3.2 Angle of rain inclination

The inclination angle of the raindrop relative to the vertical direction was defined as (Helming, 2001):

$$\alpha = \arctan(WV/TV) \tag{3}$$

where: $\alpha$ is the inclination angle of the raindrop relative to the vertical direction (°); WV is the wind velocity (m/s); and TV is the vertical raindrop velocity (m/s).

The vertical raindrop velocity, needed for equation (3), is dependent on the diameter of the raindrop and can be calculated with the following function (after Atlas & Ulbrich, 1977):

$$TV = 3.78\ D^{0.67} \tag{4}$$

where: D is the average diameter of the raindrops (mm).

The diameter of the raindrop can be measured with the function below (after Atlas & Planck, 1953):

$$D = 0.92\ I^{0.21} \tag{5}$$

where: I is the intensity of the rain (mm/h).

The vertical raindrop velocity and the average raindrop diameter were calculated for each observation. The rain intensity and the wind velocity are variables obtained from the meteorological data.

The higher the wind velocity, the greater the impact angle of rain inclination. That angle is significantly lower for class 1 (36.5°) than for class 2 (42.2°). Intense rainfall events, such as those included in class 1, have a larger droplet diameter. This leads to a greater vertical raindrop velocity and a smaller impact angle at the same wind velocity.

### 3.3 Spatial variability of rainfall characteristics and map of hydrological precipitation.

In this case, a spatial representation of the rainfall characteristics is not possible with the aid of an interpolation method. The four stations for which data were obtained from the RMI, are well distributed throughout Belgium, but to execute an interpolation based on four points is very inaccurate. Because of this problem, the spatial representation for the rain intensity was done with the aid of a triangulated irregular network (TIN) and for the spatial representation of wind velocity, wind direction and rain inclination, one average was used for the whole of Belgium, as no significant differences could be found between the four meteorological stations.

The basis of the cartographic analysis was a DEM (Digital Elevation Model) of Belgium obtained from a SRTM (Shuttle Radar Topography Mission)(http://srtm.csi.cgiar.org), calculating slope gradients and slope aspects which are both necessary for the calculation of the hydrological rainfall using equation (1) (Figure 6).

Sometimes a negative hydrological precipitation was obtained which corresponds to simultaneous occurrence of slopes that are steeper than the impact angle of raindrops and when the angle between both slope aspects is around 180°. This combination provides a negative correction factor, i.e. the second part of equation (1) (Figure 5). In figure 6, the negative values for the hydrological precipitation were reduced to 0. A negative hydrological precipitation is also known as the phenomenon of perfect rain shadow.

***Insert Figure 5 here***

***Insert Figure 6 here***

The hydrological rainfall is the greatest in the northwest of Belgium, thanks to its proximity to the coast with stronger winds. In the center of the country, the least hydrological precipitation was observed. When the air layers reach these areas, much moisture has already been lost due to precipitation. The variability in the south is due to the lager differences in relief, that provide very high and very low correction factors and thus a strong variation in hydrological precipitation, with high values of hydrological precipitation on the windward side and low values of hydrological precipitation on the leeward side.

### 3.4 Rill erosion data and maps

For a quantitative analysis of the volume of rills and the drainage density, we worked with relative values by sector, in order to give the same importance to all five studied spoil heaps (Table 2). The polar diagrams (Figure 7) illustrate preferential slope aspects for rill erosion.

***Insert Table 2 here***

***Insert Figure 7 here***

As hypothesized, overall the largest volume of rills and the largest drainage density occur on the southwest facing slopes, because the dominant wind direction in northwest Europe is the southwest. The slopes facing the northeast have only one third of the volume of rills of slopes facing the southwest (Table 2). Also the slopes facing the southeast (62%) and the west (50%) display many rills. The same conclusions can be drawn for the drainage density, with the largest relative drainage density on the slopes facing the southwest (94%) and the lowest drainage density on slopes facing the northwest (28%).

The last indicator for rill erosion is the mean distance of the head cut of the five uppermost rills till the top of the spoil heap. This indicator is a measure for the headward erosion in a sector. There is more headward erosion expected in the sectors that receive more precipitation, making that the rills will be closer to the top in these sectors. The rills are the closest to the top on the southeast (8.49 m) and the south (9.21 m) facing slopes. The rills are the furthest of the top on the northwest facing slopes (18.95 m).

In this study, four explanatory factors for rill erosion are considered: slope gradient, vegetation density, rock fragment cover and slope aspect. For the three of them polar diagrams (Figure 8) were created, to show the connection between the explanatory factor and the slope aspect. Table 3 shows the results of each explanatory factor by sector.

***Insert Table 3 here***

***Insert Figure 8 here***

The slope gradients on the different slopes of the spoil heaps are very similar. This is because conical spoil heaps were selected, to obtain slopes that are similar in as many parameters as possible. The slopes facing the northeast are slightly steeper than the other slopes, with an average value of 26°. The slopes facing the west are less steep. The average value for the southwest, west and northwest facing slopes is 21°.

The slopes facing the northwest en the north have the greatest relative vegetation density (63% - 84%). Also the slopes facing the west have much vegetation. The least vegetation is present on the southeast (16%) and the south (3%) facing slopes. For instance on the spoil heap Loos-en-Gohelle 1 the vegetation is mainly located on the west and north facing slopes. The location of the rills is spread over the different slopes and the vegetation seems to have little influence on the location of these rills (Figure 3)

The last explanatory factor is the rock fragment cover. The west facing slopes have on average the highest rock fragment cover (49%), as well as the slopes facing the north (48%). The lowest rock fragment cover is on the northeast (29%) and east facing slopes (30%).

A correlation matrix was created between the explanatory factors, in order to investigate autocorrelations (Table 4).

***Insert Table 4 here***

All the correlations were determined with the aid of a linear regression, except for the correlations with slope aspect, where a sinusoidal function was used.

There is a strong positive correlation between vegetation density and slope aspect (r=0.90), with the highest vegetation density on the slopes facing the north. There is also a strong positive correlation between slope gradient and slope aspect (r=0.94), with the steepest slopes facing the northeast. A striking observation is the negative correlation between rock fragment cover and slope gradient (r=-0.67).

### 3.5 Correlations between explanatory factors and indicators of rill erosion

***Insert Table 5 here***

There are only two significant correlations present between the explanatory factors and the indicators for rill erosion (Table 5). There is a positive correlation between the mean distance of the head cut of the five uppermost rills till the top and the vegetation density (r=0.71) and between the mean distance of the head cut of the five uppermost rills till the top and the slope aspect (r=0.94). The rills are usually located the furthest from the top on the slopes facing the northwest. The rills are located the nearest to the top on the southeast facing slopes.

In order to test the statistical significance of the indicators, an analysis of variance (ANOVA) was prepared.

***Insert Table 6 here***

The p-value for the relative volume of rills is 0.017, hence the slope aspect has an influence on the volume of rills at the 5% level of significance. The slope aspect has also an influence on the drainage density (p=0.019). For the last indicator, the mean distance of the head cut of the five uppermost rills till the top of the spoil heap, the p-value is 0.055.

A Post-hoc analysis (Fisher LSD-test) (Williams and Abdi, 2010) was performed for those indicators where there was a significant influence of the slope aspect on the indicator. The p-values (Table 7) show that the volume of rills on the southwest facing slopes is significantly higher than the volume of rills on the other slopes. There is also a significant difference between the southeast en northeast facing slopes. The drainage density on the southwest facing slopes is significant different from the drainage density on the other slopes.

***Insert Table 7 here***

### 3.6 Hydrological rainfall and rill erosion illustrated on Alu spoil heap

By making use of the digital elevation model of Alu and equation (1), it was possible to measure the hydrological rainfall on this spoil heap in ArcGis and to link it with rill erosion (Figure 9).

***Insert Figure 9 here***

The difference between the southwest and northeast facing slopes is very clear. The greatest amount of rills is clearly located in the zones with the highest hydrological precipitation. The slopes facing the west (±146 mm/h) and the southwest (±146.8 mm/h) receive the most hydrological precipitation for rains of class 1. On these slopes we found a volume of rills of 56% and 79%. On the opposite side, the east and northeast facing slopes, the amount of hydrological rainfall is much lower (±79.1 mm/h). Also the volume of rills is lower, with values of 14% and 3%. The values for the hydrological precipitation are not negative, so there is no question of perfect rain shadow on this spoil heap.

# 4. Discussion

The phenomenon of rain shadow is most known in mountainous areas due to orographic rainfall and on a large scale. Examples of these are deserts situated immediately behind a mountain range near the coast, such as the Atacama desert in South America (Houston and Hartley, 2003). Nevertheless rain shadow is also very common on a local scale, such as the Ardennes in southern Belgium (Figure 5) and for example on spoil heaps (Figure 9). This is a different type of rain shadow due to the rain inclination angle.

## 4.1 Potential explanatory factors of rill erosion on mine spoil heaps

### 4.1.1 Vegetation density

Bochet *et al.* (1999), Loch (2000) and Zhou *et al*. (2008) concluded that a dense vegetation cover gives a better protection against the impact of raindrops, it provides a deceleration of the runoff and an increase of the infiltration. A higher vegetation density should lead to less rill erosion. In this study there was not really a link established between the amount of vegetation on a slope and the rate of rill erosion, most probably because the spoil heaps show little vegetation on the top, which was a condition for the selection of a spoil heap.

There is a link between the vegetation density and the slope aspect (r=0.90). The slopes facing the south show a very low density, while the slopes facing the north have a high density. This corresponds with the findings of Debehault (1968). The high vegetation density on the north facing slopes is shown in figure 3 for the Loos-en-Gohelle 1 spoil heap. The southern slopes are more exposed to sunlight, making them drier. The northern slopes that receive less sunlight, will be less dry and will have more vegetation. Next to the contrast between the northern and southern slopes, there is also a contrast between the western and eastern slopes.

The west facing slopes have higher vegetation density than the east facing slopes. This can be explained by the fact that the western slopes receive more hydrological precipitation and they will be more humid. So the effect of rain shadow exerts a great influence on the vegetation. Pendleton (1949) already mentioned the shortage of water to make a normal plant growth possible: compared with the woods on the damp side of a mountain, the trees on the other side are much smaller. In a study of Osuch *et al.* (2009), areas that are shaded by rain shadow are also called ‘orographic dry areas’. The direction in which the slope is exposed, is very important for the rain distribution and the growth of vegetation.

Also there was a connection between the vegetation density and the mean distance of the head cut of the five uppermost rills till the top of the spoil heap (r=0.71). This means that the more dense the vegetation is present in a sector, the further the highest rills will be located from the top. An explanation could be that the vegetation slows down the headward erosion, which leads to the fact of rills lying further away from the top.

### 4.1.2 Rock fragment cover

There was no clear link established between rock fragment cover and volume of rills in this study. This is probably because a rougher surface can both increase or decrease the amount of erosion. Moldenhauer and Kemper (1969) stated that a rough surface ensures that the soil is loosened less rapidly by the impact of rain drops. Also a rough surface provides a higher storage of rainfall aboveground and it reduces the flow. This will result in less rill erosion. On the other hand Abrahams and Parsons (1990) state that on rough surfaces the flow will often concentrate, leading to more erosion and more rills.

The rock fragment cover (Figure 8, section 3.4) is more widespread than the vegetation on the different slopes. There is a difference between the west and east facing slopes, with a higher rock fragment cover on the western slopes and a lower rock fragment cover on the eastern slopes. The west facing slopes receive a greater amount of hydrological precipitation than east facing slopes. This leads to the fact that on the western slopes more fine soil is transported away and the phenomenon of lag deposit (armouring) will occur (Morin *et al.*, 1981). So a trend was observed between the rock fragment cover and the slope aspect, with a higher rock fragment cover on the slopes facing the dominant wind direction. Canfield (2001) reached the same conclusion, with a higher rock fragment cover on the eastern exposed slopes in an area with a dominant east wind.

The rock fragment cover and the slope gradient show a clear negative correlation in this study (r=-0.67). When dumping the tailings on the spoil heaps, the stones on the steep slopes roll further down, making the rock fragment cover on the top of these slopes very low (Davison, 1888; Debehault, 1968; Statham, 1972). It can also be assumed that, a long time after dumping, a stone that starts moving has more chance to roll down on steeper slopes.

### 4.1.3 Slope gradient

The slope gradient is determined by the way the tailings were poured out. The average slope gradient for the different slopes is very similar. The slopes facing the northeast are slightly steeper (26°). Nyssen and Vermeersch (2010) have already shown, that there exists only a weak correlation between magnitude of slope processes and slope gradient on spoil heaps. This is because the slope gradient on the spoil heaps hardly differ. The conclusion of Nyssen and Vermeersch (2010) can be confirmed in this study. The slope gradient has therefore a similar impact on the amount of rill erosion on the different slopes. The difference in the amount of rill erosion on the spoil heaps will not be explained by the slope gradient, except when slopes are steeper than the angle of repose, such as in the case of the Hasard spoil heap (section 2.4). The slope gradient also can have a direct influence on other factors. For example the rock fragment cover, which is much lower on the steeper slopes.

### 4.2 Importance of slope aspect for rill erosion

Because the dominant wind direction in Belgium and in the northern of France is the southwest (Figure 4, section 3.1) and this wind carries much of rain with it from the Atlantic, the biggest volume of rills is expected on the southwest facing slopes. This is the fact for the four spoil heaps studied in the northern of France. For the spoil heap Alu in Belgium, the slope facing the southwest has the second largest volume of rills.

The ANOVA-test proves that the slope aspect has an influence on the volume of rills: the volume of rills on the southwestern slopes is significant higher than that of the other slopes (Table 7, section 3.5). This can be explained by the fact that these slopes receive the greatest amount of precipitation, with the result that there is a greater volume of rills formed. For the drainage density, the same conclusions can be taken. Noteworthy is the high drainage density on the slopes facing the southeast, for which there seems to be no clear explanation.

The northeast facing slopes have generally the least volume of rills, due to the effect of rain shadow. A mirrored pattern can also be confirmed between the west facing slopes and the east facing slopes, with a high amount of rills on the western slopes and a low amount of rills on the eastern slopes.

For the spoil heap Alu, the relative volume of rills on the southwestern slope is 79%. On the northeastern slope this volume of rills is only 3%. The big difference can be explained by the amount of hydrological rainfall, which is greater on the southwestern slope (146.8 mm/h) than on the northeastern slope (79.1 mm/h) (Figure 9, section 3.6). From this it can be concluded that the northeastern slope received 53.9% less precipitation than the southwestern slope. Nevertheless, the largest volume of rills was measured on the southeastern slope. This slope receives less hydrological rainfall than the southwestern slope. As stated in section 4.2 the volume of rills is also determined by other factors.

A significant correlation was found between the mean distance of the head cut of the five uppermost rills till the top and slope aspect (Table 5, section 3.5). The rills are located the furthest away from the top on the northwestern slopes. This is related to the positive correlation between vegetation density and the mean distance of the head cut of the five uppermost rills till the top of the spoil heap. The more vegetation, the less headward rill erosion and the farther the rills will be located from the top. The rills are the closest to the top on the southeastern and southern slopes, where there is more headward erosion, due to the low vegetation density. This low vegetation density is the result of the lower amount of hydrological precipitation received by these slopes.

On the basis of the mean distance of the head cut of the five uppermost rills till the top, it is possible to determine the size of the basin that is necessary in order to lead to rill erosion. In this study a comparison was made between the northeastern and southwestern slope. For the southwestern slope a basin size upslope of the headcuts was measured of 46.73 $m^2$ and for the northeastern slope it was 81.26 $m^2$. The size of the basin on the southwestern slope is less than the size of the basin on the northeastern slope in order to lead to rill erosion, because there is a greater amount of hydrological precipitation on the southwestern slope.

From this it can be concluded that on the northeastern slopes 42.5% less precipitation is expected than on the southwestern slopes.

## 5. Conclusions

A study on five spoil heaps was carried out to determine the influence of slope aspect on hydrological rainfall and on the magnitude of rill erosion in Belgium and the north of France. The southwest is the dominant wind direction in Northwest Europe; these winds bring large amounts of precipitation with them from the Atlantic Ocean. Due to the difference in the impact angle of the raindrops on the windward and leeward sides, the windward side receives a greater amount of hydrological precipitation than the leeward side. As a result, there is a difference in the amount of rill erosion between these two sides, with more rill erosion on the southwest (96%) and west facing slopes (50%) than on the northeast (32%) and east facing slopes (36%), where the effect of rain shadow is present. A greater impact angle of raindrops will lead to more pronounced situations of rain shadow. This impact is greater on the spoil heaps because of their steep slopes. On the other hand it is not possible to find agricultural areas with a similar conical shape and homogeneous land cover in order to carry out an experiment.

Besides the slope aspect there were three other potential factors for rill erosion in this study: the slope gradient, the vegetation density and the rock fragment cover. These potential factors exerted relatively little influence on the amount of rill erosion. This is because we selected slopes which were similar in as many parameters as possible. It was confirmed that the slopes facing the north and the northwest have a higher vegetation density (84% and 63%), because these slopes are moister. There is a strong negative correlation between the slope gradient and the rock fragment cover (r=-0.67), with on the steep slopes a lower rock fragment cover. The last notable finding is that the rills are further away from the top on slopes with more vegetation (r=0.71). The vegetation inhibits the headward erosion of the rills.

We can conclude that the slope aspect in Northwest Europe has an impact on the amount of hydrological precipitation and the magnitude of rill erosion. But the impact of other factors must always be taken into account.

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## Table 1

| | Spoil heap LG 1 | Spoil heap LG 2 | Spoil heap Hasard | Spoil heap Houdain 1 | Spoil heap Houdain 2 | Spoil heap Alu |
|---|---|---|---|---|---|---|
| ***Location*** | | | | | | |
| Latitude N | 50° 26' 36" | 50° 26' 44" | 50° 37' 46" | 50° 27' 33" | 50° 27' 39" | 50° 25' 17" |
| Longitude E | 2° 46' 41" | 2° 46' 57" | 5° 42' 28" | 2° 33' 56" | 2° 34' 13" | 4° 16' 4" |
| Town | Loos-en-Gohelle (F) | Loos-en-Gohelle (F) | Fléron (Retinne) (B) | Houdain (F) | Houdain (F) | Alu (Anderlues) (B) |
| | | | | | | |
| ***Physical characteristics*** | | | | | | |
| Shape | Conical | Conical | Conical | Conical | Conical | Conical with flattened top |
| Area (ha) | 11 | 12 | 16 | 11 | 12 | 31 |
| Height spoil heap (m) | 60 | 70 | 90 | 37 | 47 | 28 |
| Volume ($m^3$) | 31 770 000 | | 5 300 000 | 7 235 000 | 5 545 000 | ND |
| Self-combustion | No | Isolated | Isolated | No | No | No |
| | | | | | | |
| ***Administrative characteristics*** | | | | | | |
| Start of deposition | 1894 | 1894 | ND | 1913 | 1913 | ND |
| End of deposition | 1988 | 1988 | 1971 | ± 1988 | ± 1988 | ND |
| | | | | | | |
| ***Sources of information*** | | | | | | |
| Internet | www.chainedesterrils.eu<br>www.espace-environnement.be | www.chainedesterrils.eu<br>www.espace-environnement.be | www.terril.be<br>www.espace-environnement.be | www.chainedesterrils.eu<br>www.espace-environnement.be | www.chainedesterrils.eu<br>www.espace-environnement.be | |
| Other sources | Institute Géographique National France | Institute Géographique National France | DigitalGlobe<br>Nyssen en Vermeersch, 2010 | Institute Géographique National France | Institute Géographique National France | DigitalGlobe |

## Table 2

| | Rel. volume of rills (%) | Rel. drainage density (%) | Mean distance 5 highest rills till the top (m) |
|---|---|---|---|
| **Sector 1 [N]** | 44 ± 39 | 41 ± 32 | 17.29 ± 6.15 |
| **Sector 2 [NE]** | 32 ± 19 | 43 ± 24 | 15.88 ± 7.71 |
| **Sector 3 [E]** | 36 ± 23 | 47 ± 43 | 16.36 ± 0.57 |
| **Sector 4 [SE]** | 62 ± 39 | 67 ± 39 | **8.49 ± 2.55** |
| **Sector 5 [S]** | 41 ± 17 | 43 ± 14 | 9.21 ± 4.43 |
| **Sector 6 [SW]** | **96 ± 9** | **94 ± 13** | 11.74 ± 3.43 |
| **Sector 7 [W]** | 50 ± 23 | 57 ± 9 | 14.60 ± 4.16 |
| **Sector 8 [NW]** | 45 ± 22 | 28 ± 22 | 18.95 ± 2.97 |
| **Mean** | **51 ± 20** | **53 ± 20** | **14.07 ± 3.84** |

## Table 3

| | Slope gradiënt (°) | Rel. vegetation density (%) | Rock fragment cover (%) |
|---|---|---|---|
| **Sector 1 [N]** | 23 ± 3 | **84 ± 31** | 48 ± 3 |
| **Sector 2 [NE]** | **26 ± 2** | 39 ± 36 | 29 ± 12 |
| **Sector 3 [E]** | 24 ± 4 | 21 ± 36 | 30 ± 15 |
| **Sector 4 [SE]** | 23 ± 5 | 16 ± 17 | 38 ± 12 |
| **Sector 5 [S]** | 22 ± 3 | 3 ± 3 | 47 ± 13 |
| **Sector 6 [SW]** | 21 ± 2 | 46 ± 36 | 37 ± 8 |
| **Sector 7 [W]** | 21 ± 5 | 32 ± 29 | **49 ± 16** |
| **Sector 8 [NW]** | 21 ± 4 | 63 ± 39 | 41 ± 9 |
| **Mean** | **23 ± 2** | **38 ± 26** | **40 ± 8** |

## Table 4

| | Vegetation density (%) | Rock fragment cover (%) | Slope gradient (°) | Slope aspect (°) |
|---|---|---|---|---|
| **Vegetation density (%)** | 1 | | | |
| **Rock fragment cover (%)** | 0.19 | 1 | | |
| **Slope gradient (°)** | 0.1 | -0.67* | 1 | |
| **Slope aspect (°)** | 0.90* (N) | 0.70 (W) | 0.94** (NE) | 1 |

**Table 5**

| | Volume of rills (%) | Drainage density (%) | Mean distance 5 highest rills till the top (m) |
|---|---|---|---|
| **Vegetation density (%)** | 0.06 | -0.20 | 0.71** |
| **Rock fragment cover (%)** | 0.05 | -0.12 | -0.11 |
| **Slope gradient (°)** | -0.55 | -0.27 | 0.14 |
| **slope aspect (°)** | 0.69 (SW) | 0.65 (SW) | 0.94** (NW) |

**Table 6**

| | p-value |
|---|---|
| **Volume of rills (%)** | 0.017 |
| **Drainage density (%)** | 0.019 |
| **Mean distance 5 highest rills till the top (m)** | 0.055 |

## Table 7

| | N | | NE | | E | | SE | | S | | SW | | W | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NE** | 0.469 | 0.939 | | | | | | | | | | | | |
| **E** | 0.686 | 0.75 | 0.807 | 0.792 | | | | | | | | | | |
| **SE** | 0.298 | 0.146 | 0.067* | 0.144 | 0.172 | 0.309 | | | | | | | | |
| **S** | 0.891 | 0.925 | 0.561 | 0.982 | 0.781 | 0.817 | 0.238 | 0.174 | | | | | | |
| **SW** | 0.005*** | 0.005*** | 0.000*** | 0.004*** | 0.003*** | 0.022** | 0.047** | 0.118 | 0.004*** | 0.007*** | | | | |
| **W** | 0.712 | 0.376 | 0.251 | 0.39 | 0.448 | 0.628 | 0.472 | 0.534 | 0.608 | 0.431 | 0.009*** | 0.033** | | |
| **NW** | 0.945 | 0.469 | 0.401 | 0.397 | 0.627 | 0.321 | 0.303 | 0.025** | 0.831 | 0.411 | 0.004*** | 0.000*** | 0.75 | 0.094* |

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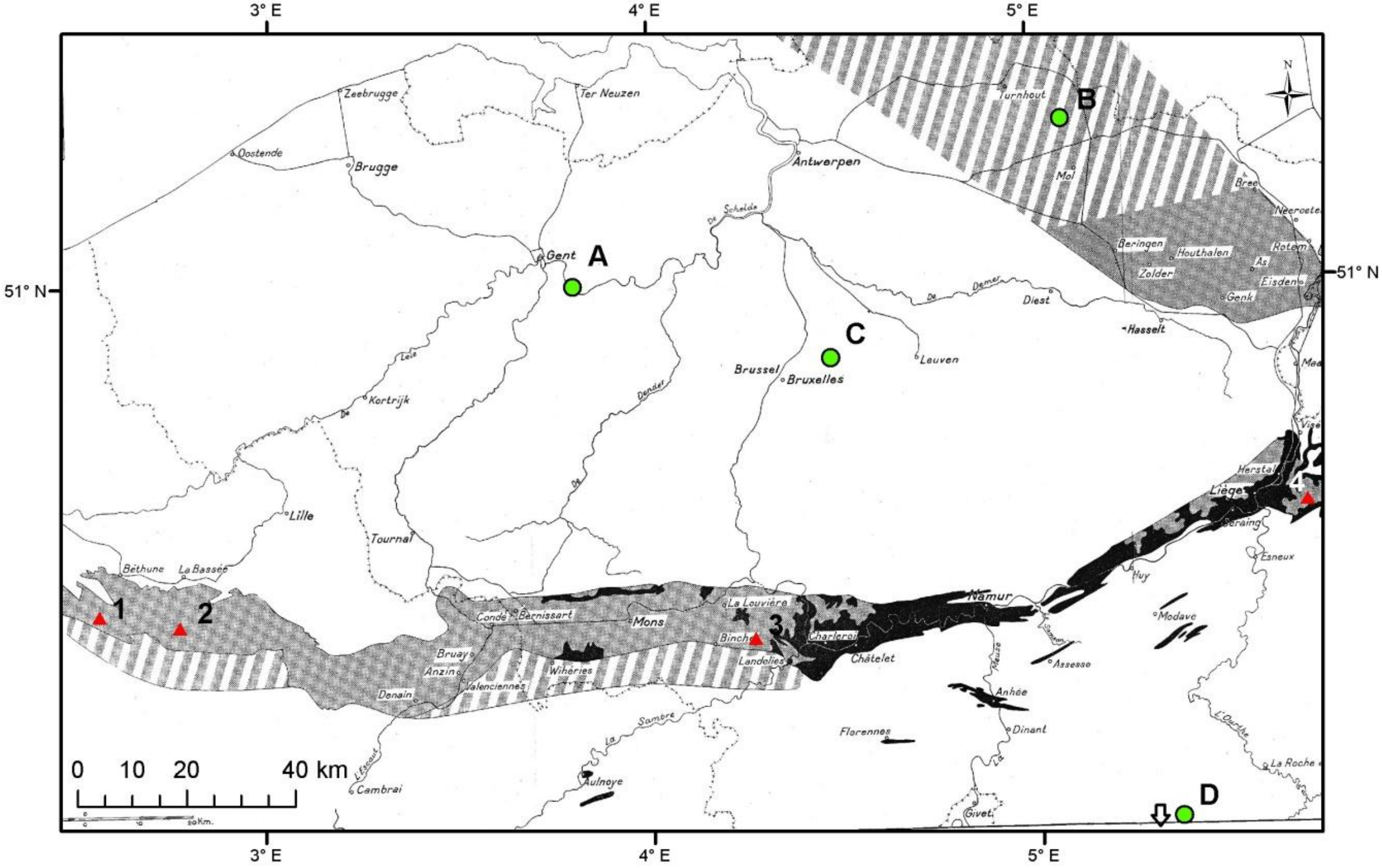
Figure 9: Map of hydrological rainfall and rills for 8 sectors (projected length: 30 m) on the Alu spoil heap.

**Figure 1**

**Figure 2**



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4° E
5° E
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Zeebrugge
Ter Neuzen
Oostende
Brugge
Turnhout
Antwerpen
Mol
Bree
Gent
Beringen
Houthalen
Zolder
Rotem
As
Eisden
Genk
Diest
Hasselt
Leuven
Brussel
Bruxelles
Kortrijk
Lille
Tournai
Béthune
La Bassée
Liège
Herstal
Seraing
Esneux
Huy
Namur
Condé
Bernissart
Mons
La Louvière
Binche
Charleroi
Châtelet
Landelies
Bruay
Anzin
Denain
Valenciennes
Wihéries
Modave
Assesse
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La Roche
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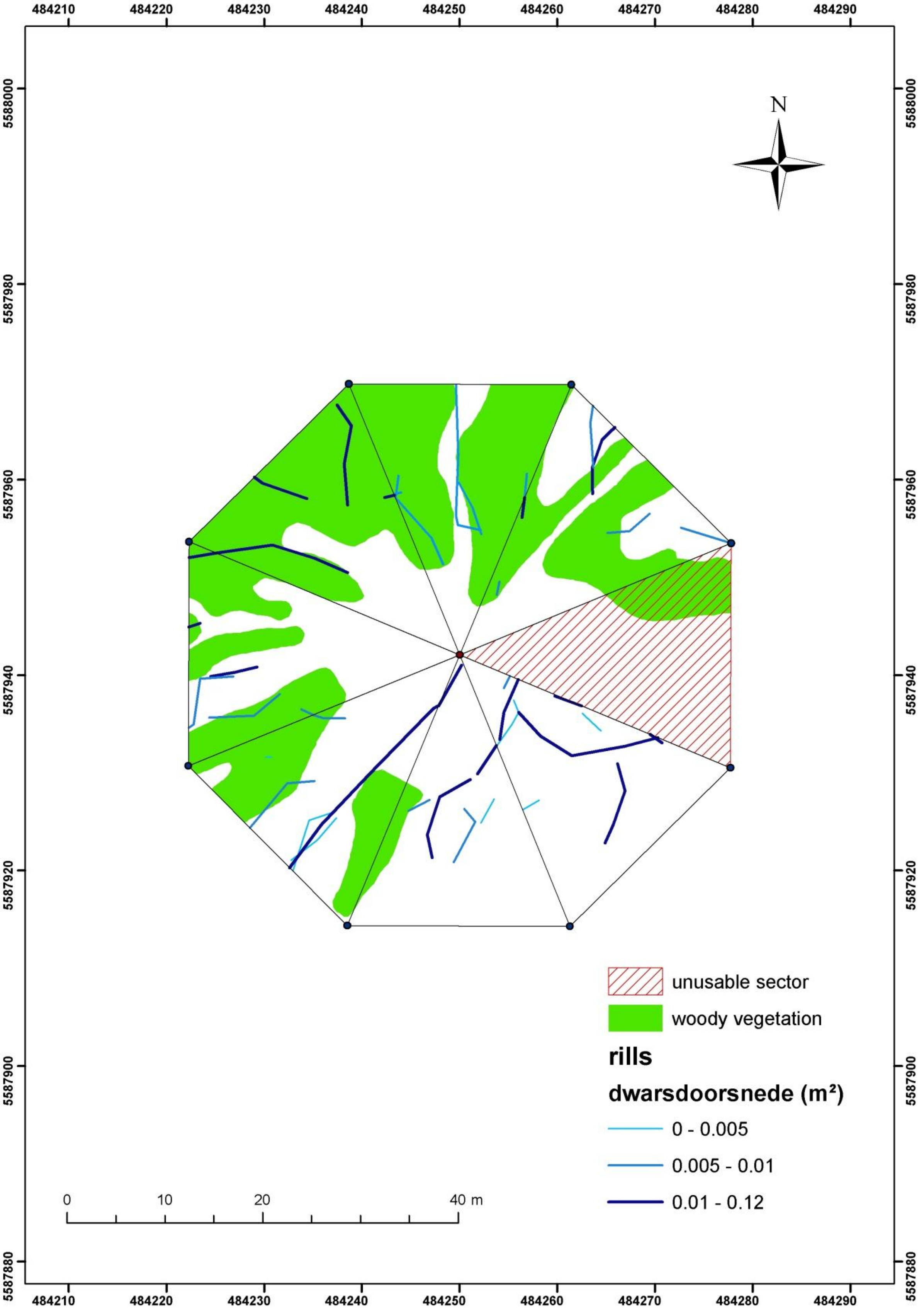
**Figure 3**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0.005 - 0.01
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**Figure 4**

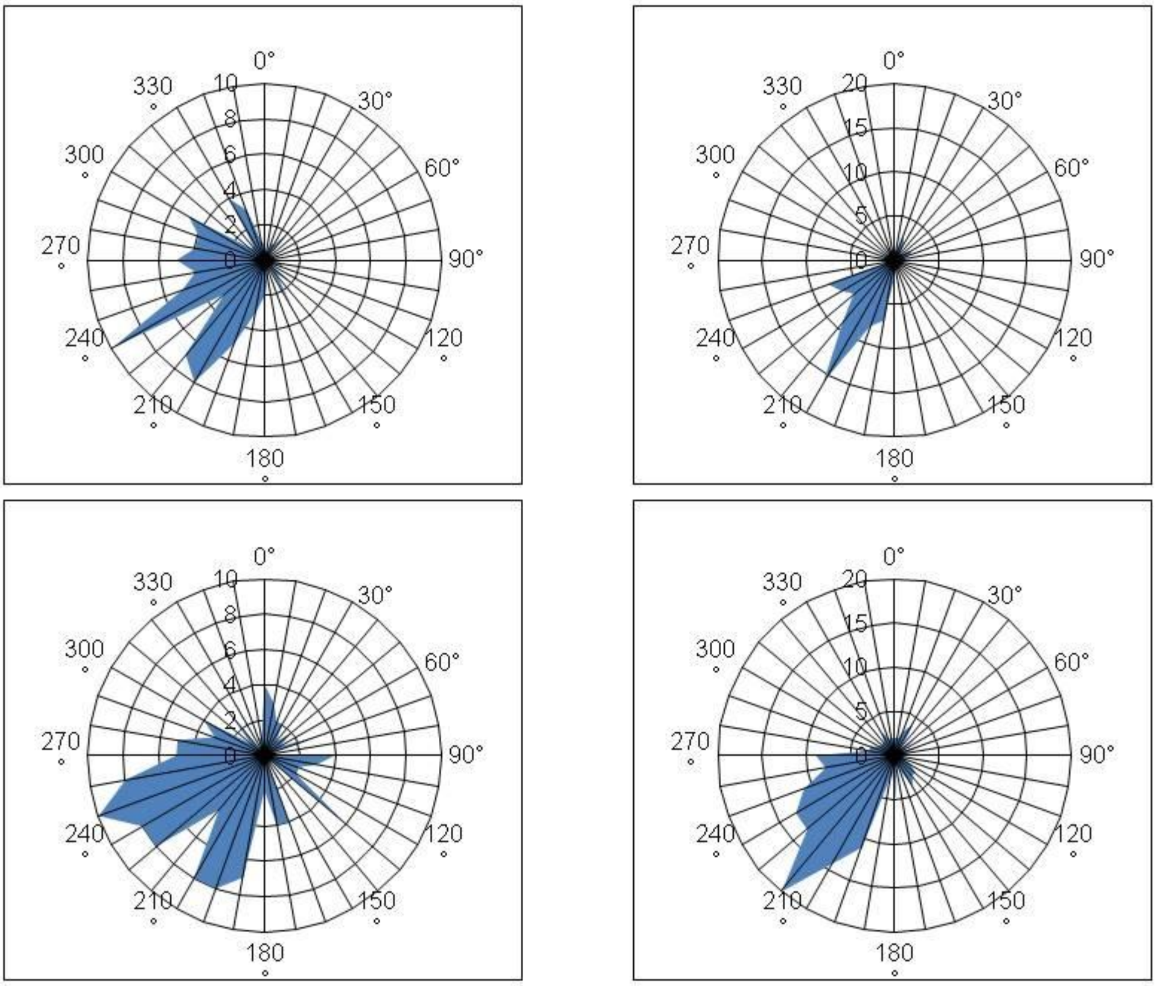
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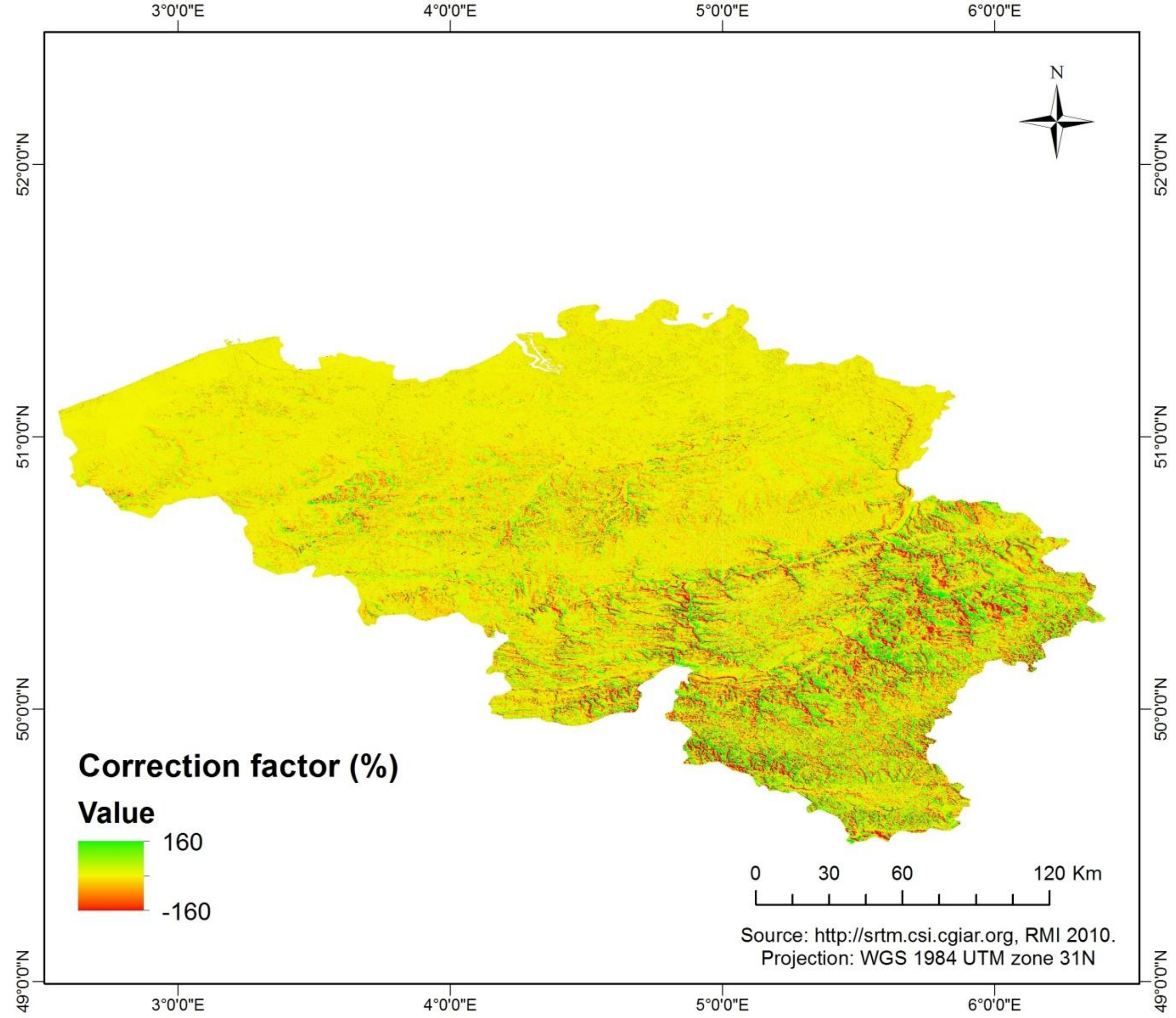
**Figure 5**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N
Correction factor (%)
Value
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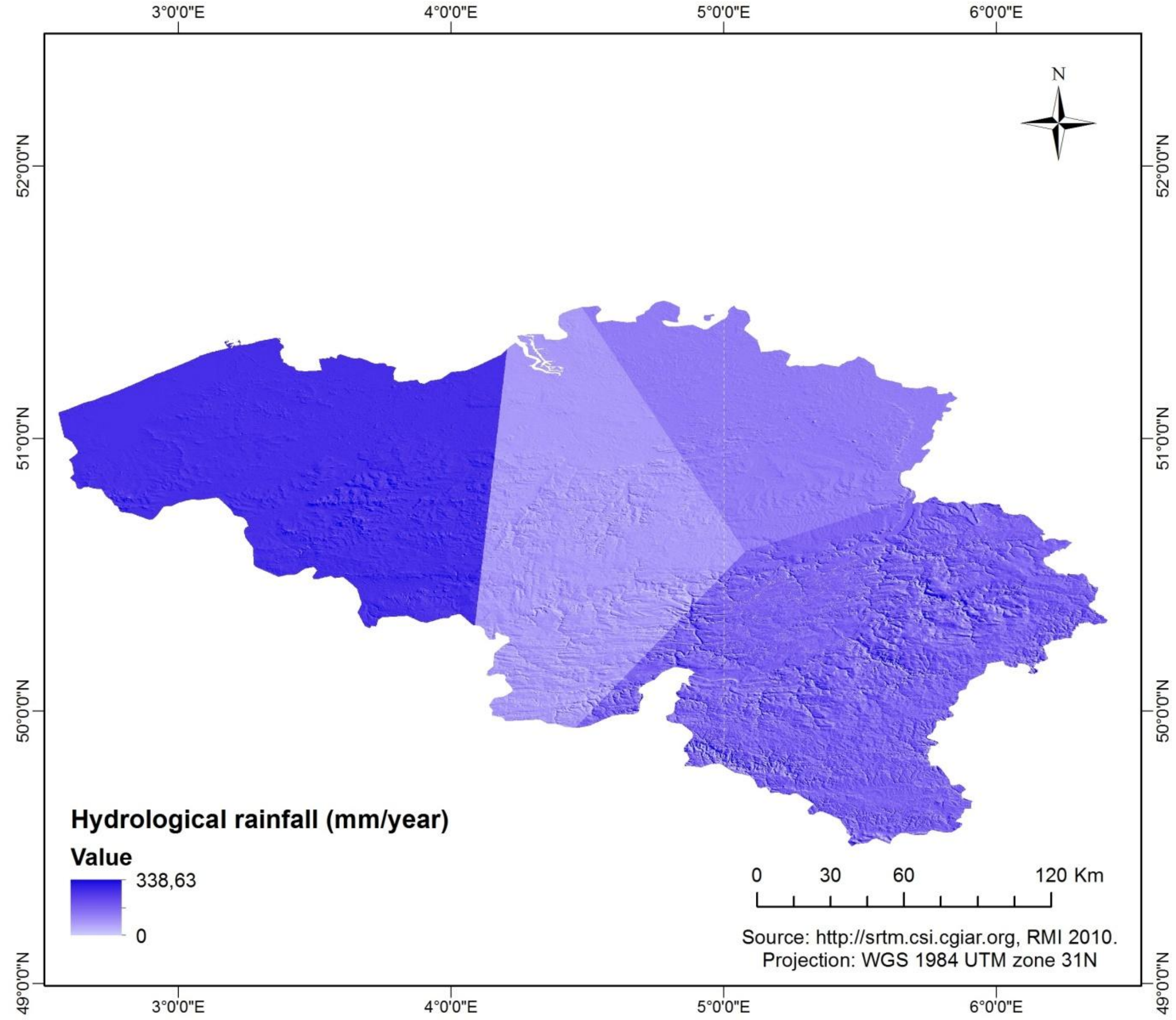
Source: http://srtm.csi.cgiar.org, RMI 2010.
Projection: WGS 1984 UTM zone 31N

## Figure 6



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## Figure 7

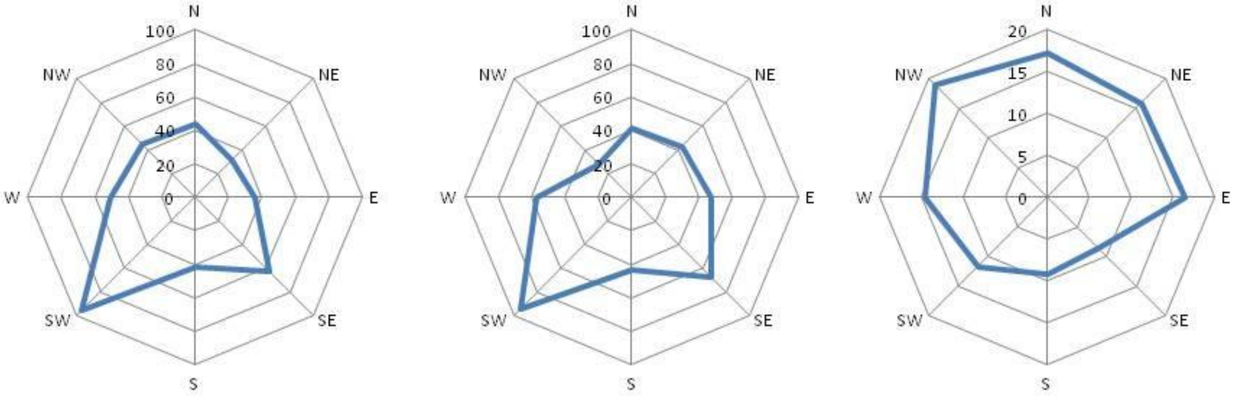

**Figure 8**

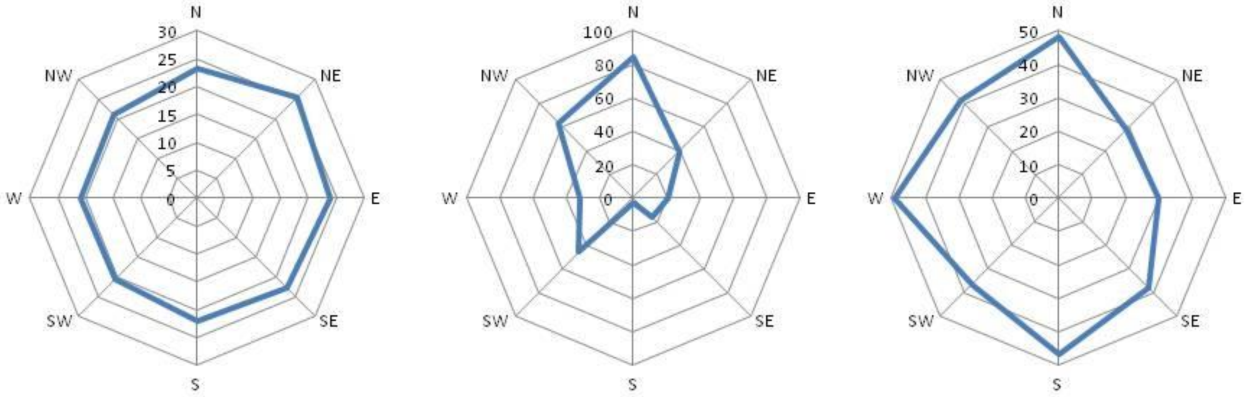
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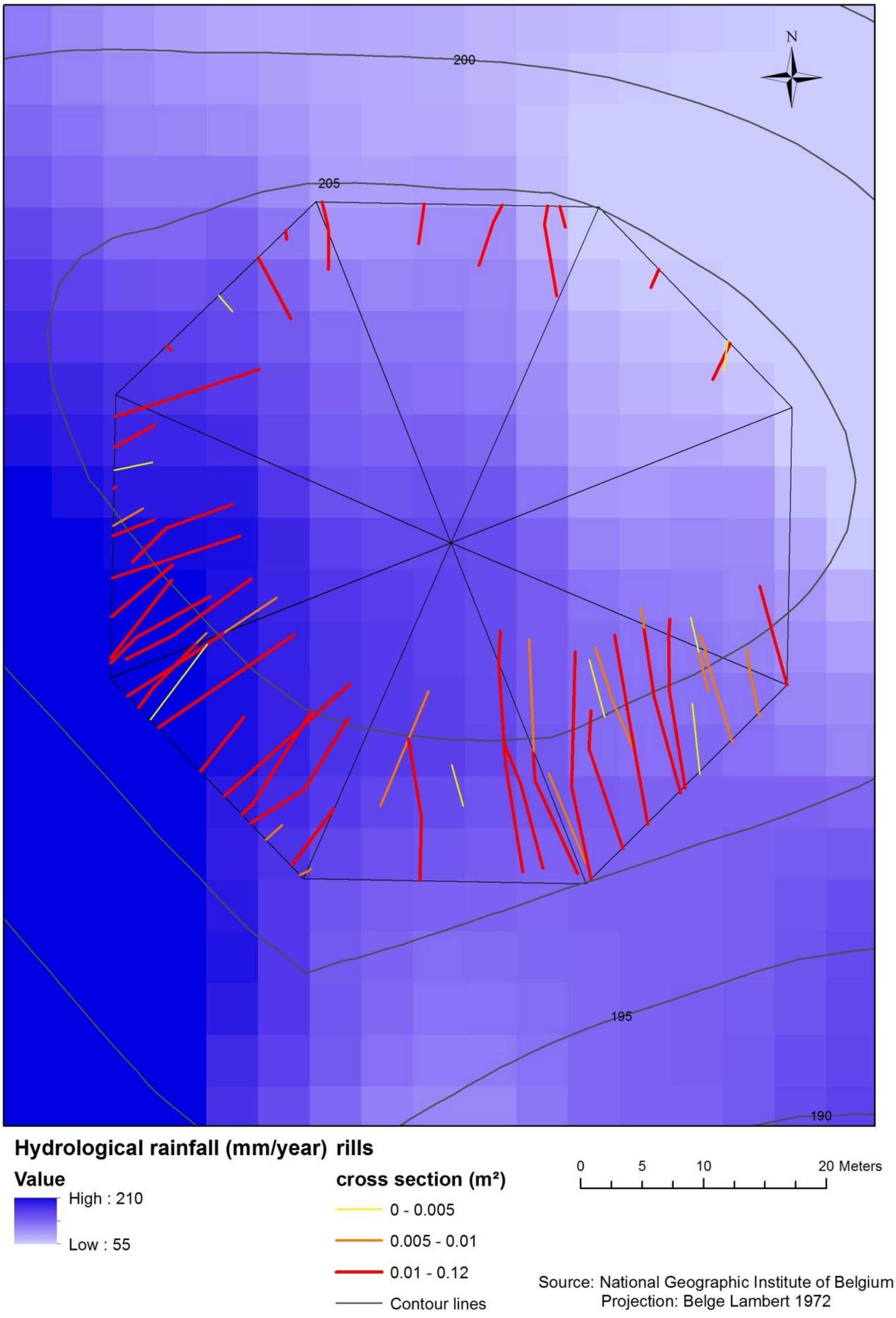
**Figure 9**



Source: National Geographic Institute of Belgium
Projection: Belge Lambert 1972