Royal Netherlands
Meteorological Institute
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Comparison of KNMI and Hellmann manual rain gauges

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Contents

Summary

In this experiment we compared two types of (commercially available) Hellmann manual rain gauges (two of each type) with two variants of the KNMI manual rain gauges (two of each variant) plus one KNMI manual rain gauge in a WMO pit. The experiment took place on the KNMI test field in De Bilt lasting from January 2020 to October 2021. The difference between the KNMI reference gauge and the Hellmann gauges appeared small compared to inter-gauge differences. Part of these differences are due to deviations in the orifice areas of the gauges and deviations in the readings of the measuring cylinders. It is concluded that the Hellmann manual rain gauge is a good replacement of the KNMI manual rain gauge. In case of a replacement, it is advised to perform parallel measurements at representative locations in the Netherlands, with a duration of two years. Observers need extra instructions to perform the measurements with the Hellmann gauge.

CHAPTER 1

Introduction

1.1 Background

In the period 2012-2014 new rain gauges of KNMI design were installed on the 320 stations of the KNMI manual daily rainfall network. In the beginning of 2017 it turned out that part of the gauges were probably leaky as a result of a design fault. Within two months all stations were inspected. During the inspections the (potential) leakiness of the rain gauge at each station was determined. Awaiting the installation of newly manufactured gauges (without shortcomings) all 320 gauges were sealed in June-July 2017 using a special tape to prevent leakage.

A study was undertaken to determine the leakiness of the gauges in the 2012-2017 period [2]. In the end, the data from 65 of the 320 rainfall stations were corrected. The underlying daily time series of the 65 stations were corrected and replaced in the KNMI climatological database. In addition, the derived operational products were adapted and republished.

The sustainability of the sealing of the gauges was not known and the fabrication of the KNMI designed rain gauge turned out not feasible. Therefore, it was suggested to search for an alternative to the KNMI manual rain gauge. A quick scan was made of manual rain gauges in use by weather services in neighboring countries. This revealed that the Hellmann manual rain gauge is of similar design as the KNMI gauge and might be a good candidate to replace a KNMI gauge if needed. The Hellmann gauge is a well-known commercially available gauge, used by, for example, the German Weather Service (DWD).

1.2 Objective and scope

The objective of this experiment is to test if the Hellmann manual rain gauge can be used as a replacement of the KNMI manual rain gauge. The experiment was performed on the test field of KNMI in De Bilt and ran from January 2020 through October 2021. The experiment coincided almost completely with the Covid period. In this period KNMI staff had limited access to the test field in De Bilt. Consequently, the manual measurements were made irregularly and mostly constituted of multi-day amounts. Studying individual events was therefore not feasible.

Chapter 2

Instrument setup and methods

2.1 Instrument setup

For the experiment we ordered two different versions of the Hellmann manual rain gauge, both constructed according to the requirements of the German weather service (DIN 58666). The first version consists of two gauges made of stainless steel in use by the DWD. These were obtained from Franz Ketterer Feinmechanik, Sölden. The second version consists of two gauges made of zinc, produced by Lambrecht and obtained from Bakker & Co, Zwijndrecht. The DWD version of the Hellmann gauge is shown in Figure 2.1.

The four Hellmann gauges have been compared with five KNMI gauges. Two of these gauges were of the old design (< 2012) and three of the new design (≥ 2012). Figure 2.2 shows an example of an old design KNMI gauge. Note that the Hellmann gauge has a separate plastic container in the reservoir. Rainfall is collected in this container and emptied into the measuring cylinder. Excess rainfall is stored in the reservoir. For the KNMI gauge, rainfall is collected in the reservoir and emptied in the cylinder. Using a separate container in the reservoir may reduce evaporation, as it protects the stored rainfall from heating up.

For the new design KNMI gauge, the height of the reservoir was increased to contain 150 mm of rainfall compared to the 115 mm of rainfall previously. The poles carrying the gauge were lowered 3.5 cm to leave the rim at the operational height of 40 cm above ground level. As only these poles have been used in the experiment, the rim of the old design gauge was at about 37 cm above ground level during the experiment.

Figures 2.3 and 2.4 show a photograph and map of the setup at the KNMI test field. Details of the gauges are in Table 2.1. One of the new design KNMI gauges was placed in a WMO pit, all other gauges were in a set-up on the field. The gauge in the WMO pit is meant to give an impression of the wind error

Figure 2.1: Left: Hellmann manual rain gauge (collecting surface 200 cm2) consisting of a reservoir (lower part) and a funnel (upper part). Right: Funnel and reservoir taken apart, the plastic container and the measuring cylinder. For the manual evaluation of the daily precipitation amount, the funnel is removed from the reservoir. Thereafter the container is emptied into the measuring cylinder.

Figure 2.2: Left: KNMI manual rain gauge (collecting surface 200 cm2) consisting of a reservoir (lower part) and a funnel (upper part). Right: Funnel and reservoir taken apart and the measuring cylinder. Before each measurement the funnel is removed from the reservoir and the reservoir is emptied into the measuring cylinder.

of the other gauges. It is known that the wind error may be as large as 2–10% for rainfall and 10–50% for snow [4]. The magnitude depends on factors like gauge shape, gauge rim height above ground level, wind speed and vertical velocity of precipitation.

We used identical plastic measuring cylinders (DIN 58667 D) to measure the rainfall of each of the nine gauges. Every gauge had its own cylinder. The rim of all gauges is at a height above ground surface as close as possible to the operational height in the Netherlands of 40 cm above ground level.

The orifice area of all gauges has been measured. In addition the reading accuracy of the measurement cylinders has been determined. The measurement uncertainty resulting from these two sources equals about 3%. The results are presented in Appendix A.

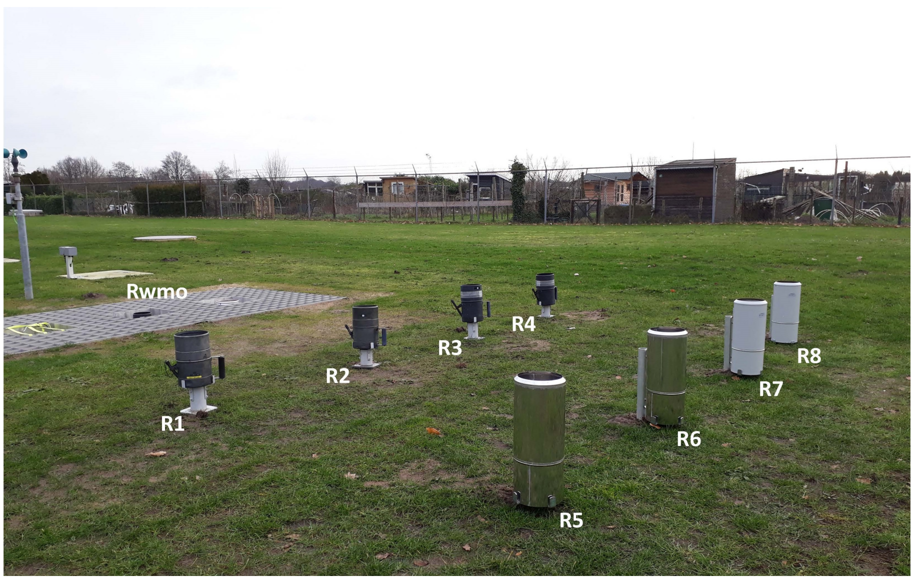

Figure 2.3: Experimental set-up at the KNMI test field in De Bilt. Photograph taken in northeasterly direction. Table 2.1 contains a description of the gauges.

2.2 Methods

Measurements

The inter-comparison of the nine rain gauges on the KNMI test field in De Bilt lasted from January 2020 to October 2021. On average one measurement was

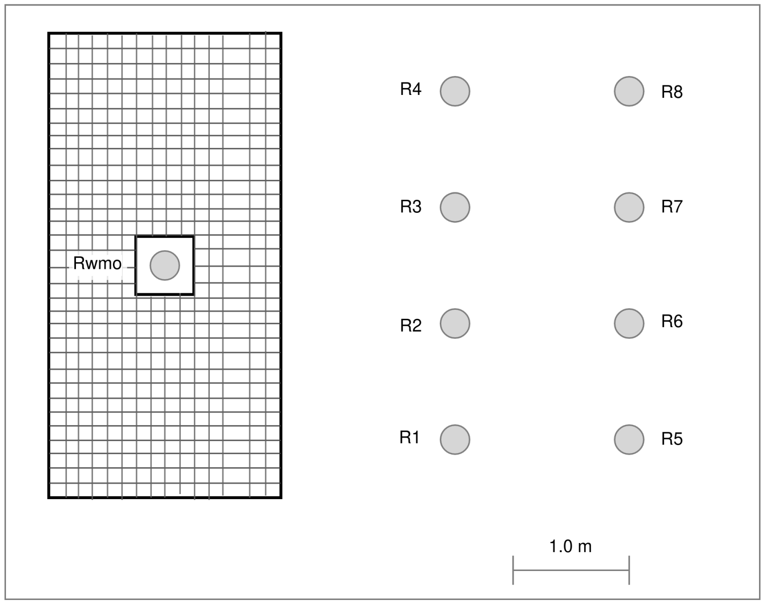

Figure 2.4: Map of the experimental set-up.

made every four days. Consequently a study of individual events – taking into account rainfall intensity and windspeed – was not feasible.

KNMI staff, experienced in measuring rainfall, performed the measurements. These took place on selected days between 8:30 and 16:00 local time, mostly around early afternoon and always during a dry period. A measurement constitutes the accumulated rainfall since the previous measurement. All measurements were checked for quality and stored in an Excel file, together with the date and time of the measurement and peculiarities, if any.

Data preparation

Data was prepared taking into account the peculiarities noted in the Excel file. The following measurements needed special treatment.

- During the measurement of 5 February 2020 the plastic container of R8 fell on the ground. Therefore the measurements on this day have been marked as not available (NA) for all gauges. It concerned 1 day of rainfall with an average of 5.9 mm in the other gauges.

- During the measurement of 19 November 2020, the cap on the funnel of R2 was stuck and rain could not be measured. On 20 November the problem was fixed and a 2-day amount was measured for R2. To make

Gauge	Type	Capacity (mm rainfall)	Gauge height (cm)	Rim height (cm)
R1	KNMI (< 2012)	115	29	37
R2	KNMI (< 2012)	115	29	37
R3	KNMI (>= 2012)	150	29	40
R4	KNMI (>= 2012)	150	29	40
R5	Hellmann (DWD)	60 (210)	45	50
R6	Hellmann (DWD)	60 (210)	45	50
R7	Hellmann (Lambrecht)	60 (210)	45	50
R8	Hellmann (Lambrecht)	60 (210)	45	50
Rwmo	(KNMI (>= 2012)	150	29	0

Table 2.1: Description of the nine rain gauges used in the experiment. The rim height is the height of the rim above ground level. The orifice area of all gauges is 200 cm^2. The capacity of the Hellmann gauges equals the capacity of the plastic container. The capacity of the reservoir, including the container, is given in brackets.

the measured rainfall of all gauges comparable, the 19 November rainfall of the other gauges was included in the rainfall 20 November.

- The measurement of 18 February 2021 is the sum of the interval 5–18 February. This was the only period with snow and ice and will be considered separately. The maximum snow depth in this period was 8 cm

Analysis

The analysis is restricted to an inter-comparison of the rainfall sums of the nine rain gauges. We use the old design manual KNMI gauge R1 as a reference.

Percentage differences were calculated as:

$$PD = 100\frac{P_{RN} - P_{R1}}{P_{R1}} \tag{2.1}$$

where P_{RN} is the rainfall of rain gauge RN and P_{R1} the rainfall of the reference gauge R1 (for the gauge numbers see Table 2.1).

Chapter 3

Results

3.1 Time series

Figure 3.1 shows the frequency distribution of rainfall amounts of the reference gauge R1 in the measurement period January 2020 - October 2021. The figure demonstrates the existence of multi-day rainfall amounts. On the one hand, low values are relatively rare. Zero rainfall for instance – within the $[0, 2.0]$ mm category – is measured only three times, where normally about half of the days have zero rainfall. On the other hand, large values (≥ 20 mm) are relatively common.

Figure 3.2 shows the time series of percentage differences. Rainfall is ag-

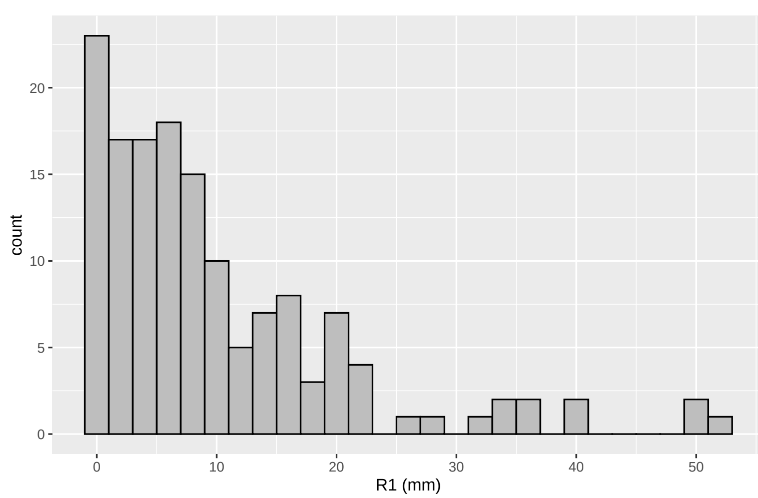

Figure 3.1: Histogram of rainfall amounts of the reference gauge R1. Each bin has a width of 2 mm.

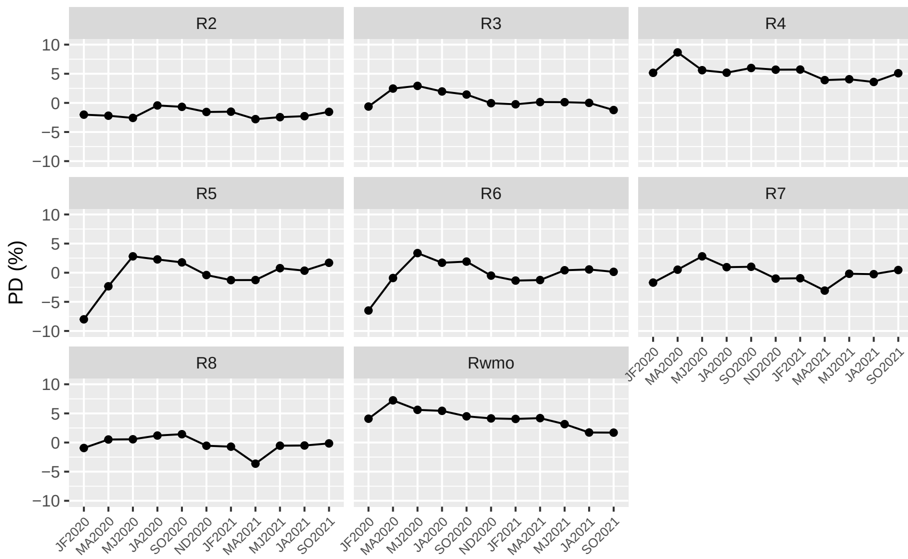

Figure 3.2: Time series of percentage differences of 2-monthly rainfall sums. Gauge R1 is the reference.

gregated to 2-monthly rainfall sums to obtain stable percentage differences. Some of the gauges show deviant behavior. Of the KNMI gauges R1–R4, R4 receives about 5% more rainfall than the others. This is unexpected. KNMI gauge Rwmo receives about 4% more precipitation. This was expected as this gauge is in the pit and, therefore, not prone to the wind error. Of the Hellmann gauges R5 and R6 (the stainless steel versions) show deviant behavior in JF2020 and MA2020. The percentage differences are strongly negative in these months, up to 8% (R5) in JF2020. From MJ2020 onward the underestimation disappears.

It is of interest to look at individual measurements in more detail to analyse the deviant behavior of the R5 and R6 gauges. Figure 3.3 shows the time series of percentage differences of all cases where Rwmo receives ≥ 5 mm rainfall. The figure shows the deviant behavior of R5 and R6 is restricted to the early period of the measurements. We assume this behavior is the result of some protective coating on the stainless steel Hellmann gauges which weathers slowly once the gauges are in the field. We therefore decided to leave out the measurements in the January-April 2020 period from the comparison.

Figure 3.3 shows an outlier that deserves some attention. It concerns the measurement on 16 April 2020. The percentage differences are up to 34%. The measurement on 16 April consists of the accumulated rainfall in the period 13 March - 16 April. This period was very dry (only 5.6 mm of rainfall

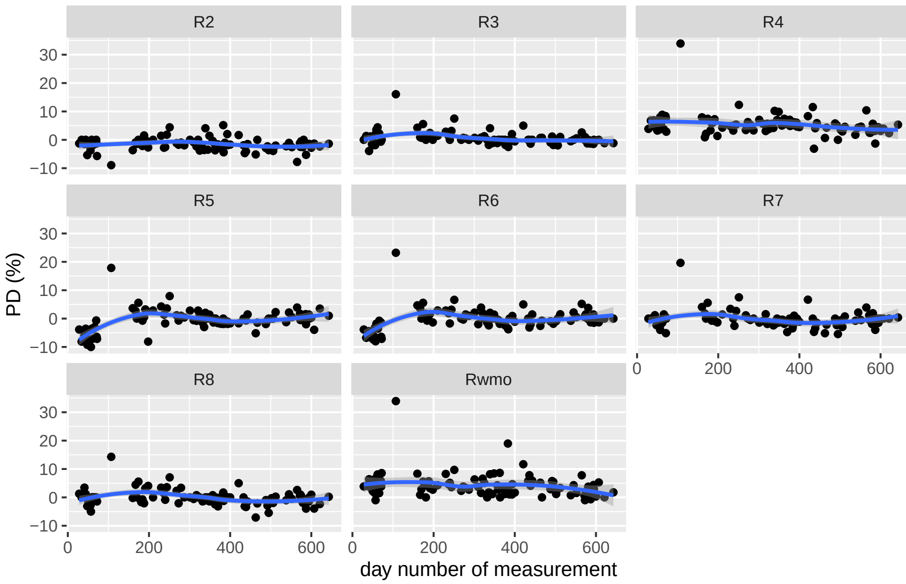

Figure 3.3: Time series of percentage differences of all individual measurements (Rwmo ≥ 5 mm.). Day number indicates the moment of reading the accumulated amount.

in R1) and sunny. The measurements of the automatic gauge close to the experimental site, show that the majority of rainfall occurred in the beginning of the period. It is therefore suggested that inter-gauge differences in evaporation errors may have caused the outlier. Evaporation errors may amount to 0–4% [4]. When accumulated over a longer period (where rainfall occurred in the beginning of the period), this may result in large percentage errors. Apparently, the old design KNMI gauges R1 and R2 are most sensitive to the evaporation loss error.

3.2 Dependence on rainfall amounts

Figure 3.4 shows the dependence of the percentage differences on the magnitude of the rainfall amounts. Due to the small number of groups the slopes of all regression fits in this figure are not significantly different from zero. Nonetheless the figure gives relevant information. First, for all gauges, except R2 and R8, there is a tendency for percentage differences to be larger for the smallest rainfall amounts (≤ 2 mm). This might partly be related to the differences in evaporation errors in the previous section.

Second, the large percentage errors for R4 are present for the whole range

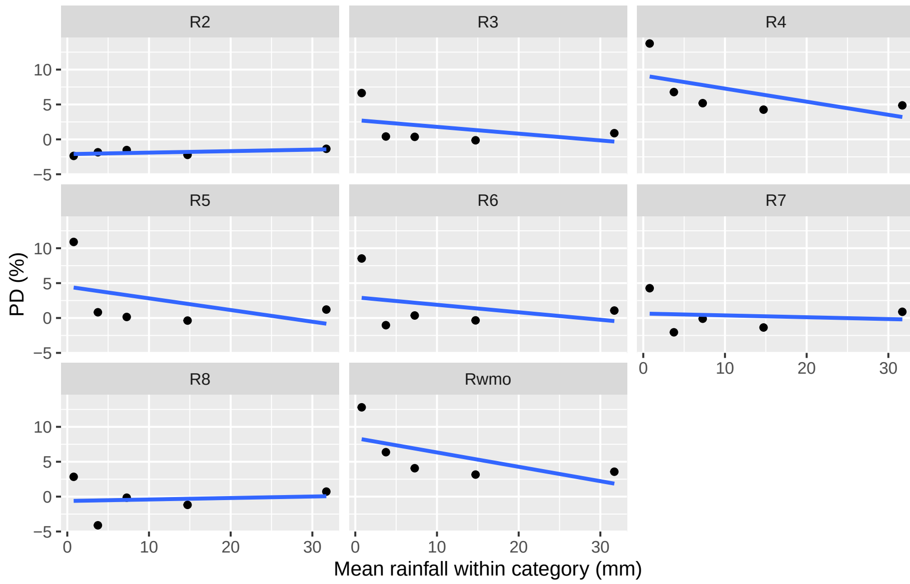

Figure 3.4: Relationship between rainfall amount and percentage difference. Rainfall amounts are summarized for rainfall measurements of Rwmo (mm) in each of five categories: $(0,2]$, $(2,5]$, $(5,10]$, $(10,20]$, $(20,\infty]$. The straight lines show a linear regression fit.

of rainfall amounts. This deviation is difficult to explain and requires further study. Third, for Rwmo the percentage errors gradually increase with decreasing rainfall amounts. This is expected because smaller rainfall amounts are generally associated with smaller droplets. These droplets have lower vertical velocity than larger droplets and are, therefore, more likely to cause wind errors. Compared tot the other gauges, Rwmo is hardly affected by these errors.

Finally note that the same type of gauge (R3, R4 and Rwmo; R5 and R6; R7 and R8) show a similar behavior. The old design KNMI gauges and the Hellmann gauges (Lambrecht) show hardly dependency with amount.

3.3 Snow case

The snow case covers the period 6–18 February 2021 with snow and frost. At the end of this period the snow melted and was measured on 18 February. The reference gauge R1 measured 11.6 mm. Table 3.1 presents the percentage differences for this case.

The table shows obvious differences between the KNMI gauges on the one hand and the Hellmann gauges on the other. A special case is the KNMI gauge

Gauge	Amount(mm)	PD (%)
R1	11.6	–
R2	12.2	5.2
R3	11.4	-1.7
R4	11.8	1.7
R5	15.2	31.0
R6	14.8	27.6
R7	15.4	32.8
R8	15.7	35.3
Rwmo	35.0	201.7

Table 3.1: Accumulated amount and percentage differences of the measurement at 18 February 2021 after a period with snow and frost.

Rwmo. The latter is at ground level and especially sensitive to snowdrift. Rwmo is therefore not reliable in snow situations.

The large percentage differences between the KNMI gauges and the Hellmann gauges, is probably caused by the design of the gauges. The funnel of the Hellmann gauges is about 7 cm deeper than the funnel of the KNMI gauges and thus has more capacity to store snow. In addition, the design of the Hellmann funnel is such that snow less easily blows out of the funnel than for the KNMI gauge. In general, the Hellmann gauge is probably better designed for measuring large amounts of snow than the KNMI gauge. However, in case of snowdrift, the Hellmann gauge may tend to store more drifted snow than the KNMI gauge. As the maximum snow depth in the period was 8 cm (equalling about 8 mm of water equivalent), the Hellmann gauges probably measured far too much snow. The results for the KNMI gauges are more in line with the measured snow depth, but still indicate a some overestimation.

Snow events are rare in the Netherlands. Therefore, for the overall results in the next section, we leave out the snow case.

3.4 Overall results

Figure 3.5 shows boxplots of the percentage differences (May 2020 - October 2021). The figure shows a close agreement between the KNMI gauges and the Hellmann gauges, with the exception of R4.

The percentage differences of all measurements in the May 2020 - October 2021 period is shown in Figure 3.6 (see for details Table 3.2). With the exception of R4 and Rwmo, the differences between the gauges are small. The percentage difference for Rwmo gives an indication of the wind error at the

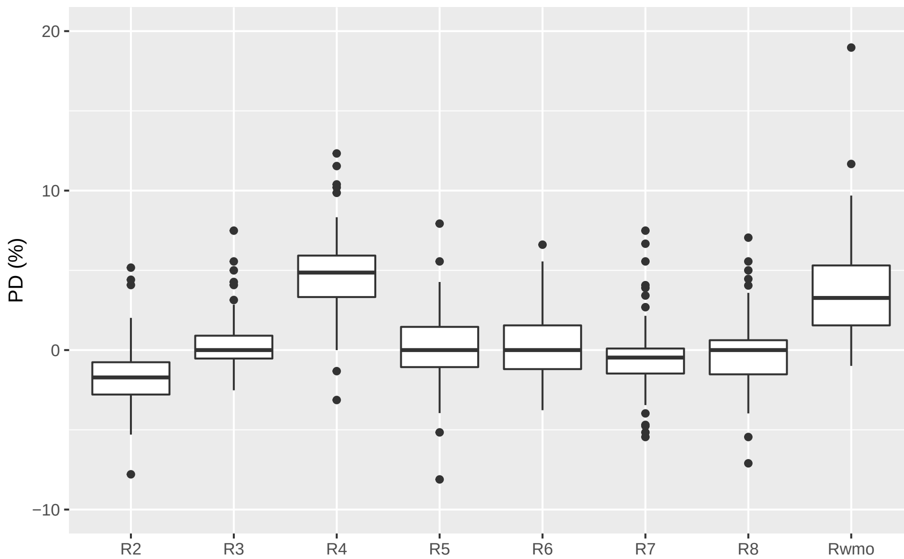

Figure 3.5: Boxplots of percentage of individual measurements (Rwmo ≥ 5 mm). A box consists of the first, second, and third quartiles. The second quartile equals the median and the distance between the first and third quartiles the inter-quartile range (IQR). The upper whisker extends from the hinge to the highest value that is within 1.5 * IQR of the hinge. The lower whisker extends from the hinge to the lowest value within 1.5 * IQR of the hinge. Data beyond the end of the whiskers are outliers and plotted as points.

observational measurement height. The anomalous behavior of R4 is, so far, inexplicable. Inclusion of the snow case only marginally affects the overall results in Table 3.2. The percentage differences of the Hellmann gauges would increase by about 0.3%.

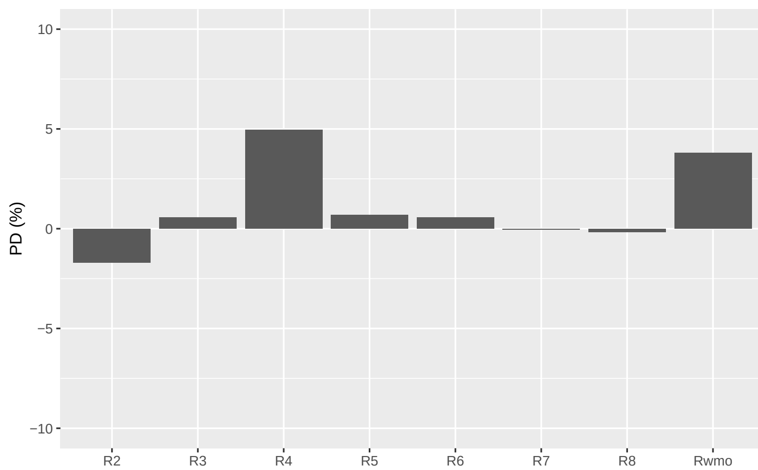

Figure 3.6: Barplot of percentage differences of the rainfall sums in the May 2020 - October 2021 period.

Gauge	Amount(mm)	PD (%)
R1	1219.8	–
R2	1199.2	-1.7
R3	1226.7	0.6
R4	1280.3	5.0
R5	1228.3	0.7
R6	1226.6	0.6
R7	1219.4	0.0
R8	1217.7	-0.2
Rwmo	1266.1	3.8

Table 3.2: Sum of alle measurements and percentage differences in the May 2020 - October 2021 period.

Chapter 4

Discussion and conclusion

In this experiment we compared two types of Hellmann manual rain gauges with two variants of the KNMI manual rain gauges plus one KNMI manual rain gauge in a WMO pit. Although the measurements apply to multi-rainfall events, due to the Covid period, we can draw some general conclusions from the experiment.

With the exception of gauge R4, the results for the KNMI and Hellman match well. The differences are small with respect to the measurement uncertainty of about 3%.

The reason for the anomalous behavior of R4 is not yet clear. Further examination in the KNMI lab did not reveal major deviations of R4 compared the other KNMI gauges. From the discussion of an outlier in Section 3.1, there is, however, an indication that small differences in evaporation from the reservoir of the KNMI gauges might (partly) be responsible for the odd behavior of R4. This was later confirmed in a two-day experiment (not shown) on the KNMI test field in De Bilt on two dry sunny summer days (28–30 June 2022). Both R3 and R4 were placed on the test field with 6 mm (120 grams) of water. After the two dry days the evaporation error was determined taking into account the wetting error. The evaporation error sum of the two days equalled 2.3% for R3 and 1.4% for R4.

Rwmo measured on average 3.8% more rainfall than the reference gauge. This corresponds well to Braak [1], who found in De Bilt an annual mean difference of 3.1% between a KNMI manual rain gauge in a WMO pit and one at 40 cm above ground level. The wind error in De Bilt, with the orifice at 40 cm above ground level, is thus about 3–4%.

For small rainfall amounts there is an indication that the evaporation error may be important. Sevruk [4] estimated this error as 0–4%. In the present experiment, the differences in evaporation error between the gauges are relatively small and probably have a minor effect on the overall results.

For snow there are large differences between the Hellmann and KNMI gauges with the Hellmann measuring more than the KNMI gauge. However, the results of all gauges seem to be affected by drifting snow. Because measurement only took place at the end of the snow and frost period, a thorough comparison for snow events is not possible. It is recommended to study this further in a future comparison, though snow events are rare in the Netherlands.

We conclude from the analysis that the Hellmann manual rain gauge is a good replacement of the KNMI manual rain gauge. In case of a replacement, it is advised to perform parallel measurements at representative locations in the Netherlands, with a duration of two years [3]. The observer needs extra instructions to perform the measurements with the Hellmann gauge. For locations in observer's gardens, the Hellmann gauge might visually be less attractive than the KNMI gauge. Perhaps painting the outside of the Hellmann gauges with a natural color may partly provide for this. Appendix B summarizes all recommendations for using the Hellmann gauge.

Acknowledgements

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Appendix A

Calibration results

Both the orifice area of the gauges and the measuring cylinders have been calibrated in the KNMI calibration lab. Here we present the results of the calibration.

A.1 Gauge

The orifice area of all gauges is 200 cm^2. Small deviations may cause errors in the measured rainfall amounts. In the lab the diameter of orifice has been measured along two perpendicular lines. The mean of the two measurements has been used as the diameter of the orifice. Table A.1 presents the results of the calibration including the measurement error.

In general the error is within 0.3%. Gauge old design KNMI gauge R2 has

Gauge	Diameter(mm)	Error (%)
R1	159.80	0.28
R2	158.65	-1.16
R3	159.50	-0.10
R4	159.50	-0.10
R5	159.70	0.15
R6	159.65	0.09
R7	159.60	0.03
R8	159.50	-0.10
Rwmo	159.10	-0.60

Table A.1: Diameter of the gauges as measured in the KNMI calibration lab and the measurement error introduced by the deviation from the standard 200 cm^2 orifice area.

the largest deviation with an error of −1.2%. Rwmo has an error of −0.6%. Positive and negative errors imply an overcatch and undercatch of the gauges, respectively.

A.2 Measurement cylinders

Identical measurement cylinders haven been used in the experiment and each gauge was measured with the same (numbered) cylinder during the experiment. Every cylinder can measure 10 mm in total with a reading accuracy of 0.1 mm. In the calibration lab, each cylinder was filled with fixed amounts of water corresponding to readings of 2, 4, 6, 8 and 10 mm. The water amounts were weighted with a scale of Satorius type CP6201 using tap water of 19°C. Forty grams of water corresponded to 2 mm of rainfall, 80 grams of water to 4 mm, etc. After filling the cylinder with water, readings were performed as in the field and the errors calculated.

Figure A.1 shows the results of the calibration. The errors resulting from the measuring cylinder are in the range of -0.5–2.5%. They are mostly positive and often decrease with increasing magnitude of the reading.

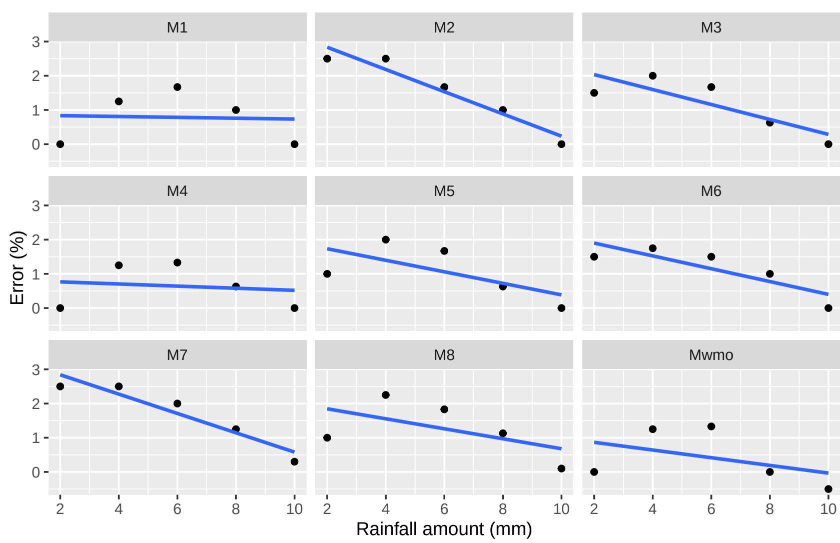

Figure A.1: Error resulting from the measuring cylinders as a function of rainfall amount in the cylinder. M1 corresponds the the measuring cylinder of R1, M2 of R2, etc. The straight line represents a linear regression fit.

Appendix B

Recommendations for Hellmann gauge

Following is a list of recommendations when using the Hellmann manual rain gauge as a replacement for the KNMI gauge.

1. The stainless steel version of the Hellmann had startup problems probably due a protective coating. It is therefore recommended to clean the gauges before placing them in the field.

2. The plastic container within the gauge may be slippery and therefore difficult to hold in one hand. It is recommended to attach a handle to the container or order a container with a handle.

3. Emptying the plastic container needs special attention to prevent drops remaining in the container.

4. The capacity of the container is only 60 mm of rainfall. Excess rainfall will spill into the reservoir (this did not occur in the experiment) having a total capacity of 210 mm. This is an advantage over the KNMI gauge which has a capacity of 150 mm. Measuring the excess rainfall of the Hellmann gauge is not difficult but requires extra instruction.

5. Compared to the KNMI gauge, the Hellmann is more bulky and one of them is shiny. The Hellmann therefore probably has a less attractive appearance in the gardens of the observers.

6. The tested Hellmann gauges were light-gray and stainless steel colored. It may be necessary to paint the outside of the gauges such that they do not stand out in the gardens of the observers.

7. The Hellmann gauge has a height of 45 cm. In the test the rim was 50 cm above the ground leaving 5 cm between the ground and the bottom of the gauge. It is recommended to increase the rim height to 55 cm. The leaves a little more space between the bottom of the gauge and the grass while only slightly reducing the rainfall amounts. The extra space facilitates growing of the grass and prevents the bottom of the gauge from getting dirty.

8. In contrast tot the KNMI gauge, which is standing on a pole, the Hellmann is attached to a pole. In case of a replacement, it is recommended to find a way to extend the existing KNMI pole so that it can be used for the Hellmann gauge.

9. In case of a replacement, it is strongly recommended to perform parallel measurements at representative locations in the Netherlands, with a duration of two years [3].

10. During the parallel measurements, it is recommended to also study the effect of pollution of the reservoir/container and funnel on the measurements.

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