A Short Note on Errors in Rainfall Measurement

G. DU T. DE VILLIERS
Department of Geography, University of Durban-Westville, Private Bag X54001, Durban, 4000

Abstract

Daily rainfall data obtained from 6 rain gauges set up in 5 different ways are analysed. The effect of wind on rainfall measurements are illustrated and the need for the correction of vertical gauge values when measuring rain on slopes is stressed.

Introduction

Records of man's first attempt to measure rainfall are lost in antiquity. Biswas (1967) notes that rainfall records were collected as early as 400 B.C. and their use indicated knowledge of rainfall amounts, crop requirements and forecasting techniques. Apparently rainfall records in some or other form have been kept for thousands of years with surprisingly little difference between measurement techniques. Ward (1975) notes that since its inception, both the principles and the purpose of precipitation measurement have remained unchanged, the aim being to intercept precipitation over a known, carefully defined area bounded by the raingauge rim, to measure the amount of water so collected, and to express this measurement in units of depth. It is then assumed that this depth of water caught by the raingauge is the same as the depth of rain falling on a large area surrounding the gauge.

Accuracy of rainfall measurement

The measurements produced by well-exposed and well-maintained standard raingauges in areas of minor relief are, for many purposes, sufficiently near the true rainfall. An objective estimate of the volume of water which passes the lowest part of the atmosphere during a given time period is obtained. The result of such measurement is objective in the sense that it is independent of the geometric position of the ground surface or the angle of incidence of raindrops. It is well to recognise however, that the catch of a standard gauge is not the true ground rainfall, namely the amount of rain which would have reached the ground if the gauge had not been there.

The errors that may arise in obtaining a representative sample at a gauge location are referred to as 'local' errors. These include splash in or out, evaporation losses, losses in wetting of the gauge surfaces and inaccuracies due to improper exposure of the gauge orifice. These errors are mostly of such a small nature that they can be ignored but the effect of wind, the major error source, should be considered in measurements where small differences in readings between certain parameters are significant. Wind consequences are not avoided by the usual method of rain gauge installation, particularly at windy sites. The gauge forms an obstacle in the path of the wind thus the wind speed is increased over the gauge orifice and a turbulent eddying effect is produced. Drop trajectories are distorted and drops are carried over the gauge resulting in an underestimate of the fall. At a wind velocity of 3,5 ms^{-1}, air speed over the gauge is increased by up to 37% (Ward, 1975). Hence, all rainfall measurements are relative, a fact not generally recognised. Loss of catch is greatest in storms with small drops and high wind speeds, while tall gauges are more susceptible to loss from wind action than short ones because of higher wind speeds around elevated gauges where the surface friction effect is lower (Court, 1960; Sharon *et al.*, 1976; Rodda *et al.*, 1976).

In an effort to reduce the rainfall distribution effects caused by the gauge in the wind, various forms of shields have been devised. The most popular of these are the Nipher shields, consisting of an inverted cone, and Alter or Tretyakov shields, which consist of a ring of slats around the gauge. The effect of wind shields on rain gauges is to divert the airflow down and around the gauge, thus minimizing updrafts, downdrafts, and turbulent eddies over the gauge orifice. These measuring problems, linked to differences in exposed heights and gauge diameters, result in uncertainties about the accuracy of rainfall data. The W.M.O. Interim Reference Precipitation Gauge was thus introduced in an attempt to provide a basis for comparison, and differences between readings from this and the various national gauges range from 5 to 15 per cent (Ward, 1975).

Measurement of rainfall in undulating terrain

A different approach should be adopted in quantifying rainfall in undulating terrain or in mountainous catchments. Here an additional element comes in, namely, the position of the rain receiving surface in relation to the paths of the falling drops. Rain falls obliquely as a result of wind action, and inclinations of 40° have been reported by Hamilton (1954) and Court (1960). Under these circumstances the windward facing slope will be more thoroughly wetted than a slope facing the opposite direction. Sharon *et al.* (1976) calculated percentage differences in catch between windward and leeward facing slopes for various inclinations of the ground and of the rain vector. These differences vary between 34% and 85%, but a difference of a factor as high as two is possible. On a macro-spatial scale it is possible for these differences to be cancelled out in the sense that what is lost on the one slope is gained on the other and the horizontal catch therefore would give a measure of the mean over the area. In many instances this does however not apply, and it thus necessitates the use of inclined gauges or gauges with the orifices lying in a plane parallel to the sloping surface concerned. Several types of stationary and rotating directional rain gauges are in use of which the installation and functioning are, amongst others, discussed by Hamilton (1954); van Heerden (1961); and Sharon *et al.* (1976). The rain vector is the basis on which the design of the directional rain gauges rests. Van Heerden (1961) states that the direction and magnitude of showers may be represented by vectors. The direction of the vectors is the same as that of the showers and their magnitude is determined by the quantity of water precipitated per unit area — the area being measured perpendicular to the direction of the rain.

Theoretical Aspects of Inclined Rain Measurements

Obviously the catch volume in an inclined gauge is determined by the relation between the gauge aperture and the storm vector. In practice this angle (T) varies continuously with fluctuations in wind speed, wind direction and drop size.

Sharon *et al.* (1976) demonstrates that the catch volume in a gauge is determined by T and the area R and diameter S of the orifice,

$$R = \frac{\pi}{4} S^2$$

When the resultant direction of drop trajectories is perpendicular to the aperture, the gauge collects a sample with diameter S (Fig. 1), identical to the gauge aperture. Any deviation from this situation results in a distortion of the rain column into an elliptical sample where the area R_1 is given by

$$R_1 = \frac{\pi}{4} d_o d_i = R \cos T$$

where

$d_o d_i$ = the change in axis of the sample column expressed as $d_i = d_o \cos T$

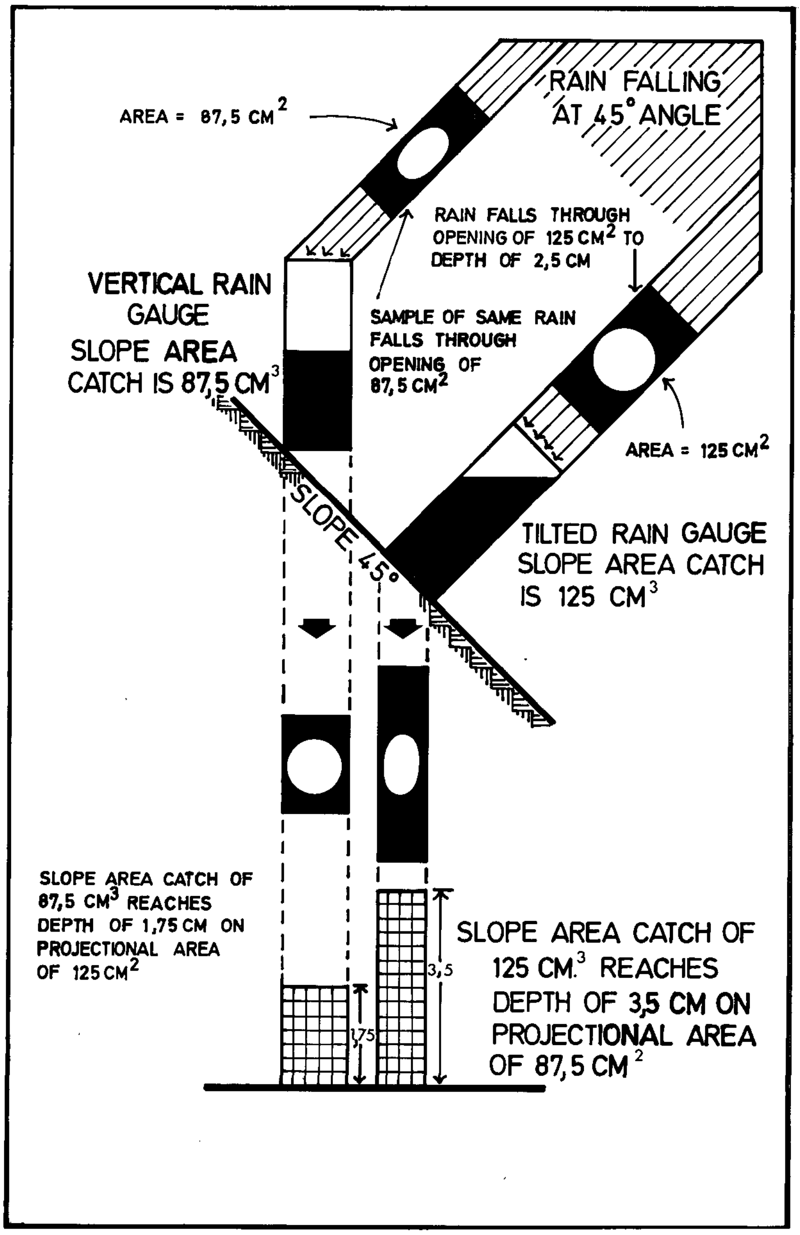

Figure 1
The correct sampling of inclined rainfall on a slope

From the above it becomes clear that inclined rainfall measurements are affected by variations in the rainfall intercepted on slopes with different gradients and aspects in relation to the falling rain. The general meso-scale wind systems as well as local wind flow patterns induced by local topography are further complicating factors.

Experimental Procedure

A rainfall measurement experiment was set up in the meteorological station of the University of Durban-Westville to quantify the variability of the catch in the various types of gauges discussed in the previous sections. The experimental site's environment is particularly suitable for this purpose because of relatively windy conditions and steep gradients. A total of six gauges were used to collect data during the 1978/79 rain season. Two of the gauges were set up in the normal vertical fashion with the orifices 1,2 m above ground level. A third was set up in the same way, but with the orifice 2,4 m above ground level. The fourth gauge was similar to the first two, but it was protected against wind effects by a Nipher screen. A pit gauge and an inclined rotating gauge completed the set-up.

The pit gauge, with its orifice horizontal, was installed at ground level after Neff (1977) for estimating the effective loss in the elevated gauges as well as for comparison with the Nipher screen gauge. The pit gauge was surrounded by plastic fibre mat to protect the gauge against splashing errors (Figure 2). The mat had the effect of a soft impact and breaking up of the drops, followed by immediate penetration through the material. It's effectiveness against splashing errors was tested with a water spray and no splash in occurred. The rotating inclined gauge was mounted on a vertical axle at an angle of 20° from zenith (Figure 3). The axle rotated in brass bushes which were mounted on a 25 mm diameter steel mast. The gauge, with its orifice 1,2 m above ground level was tilted at a 20° angle to simulate a slope effect, and thus making an assessment of slope rainfall from any given wind direction possible.

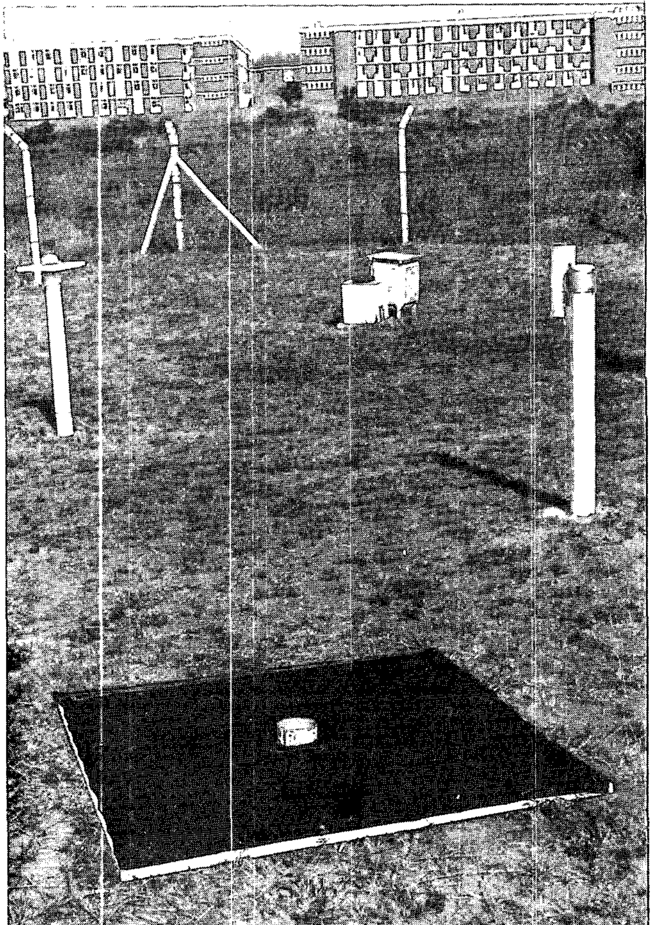

Figure 2
The pit gauge surrounded by a plastic fibre mat

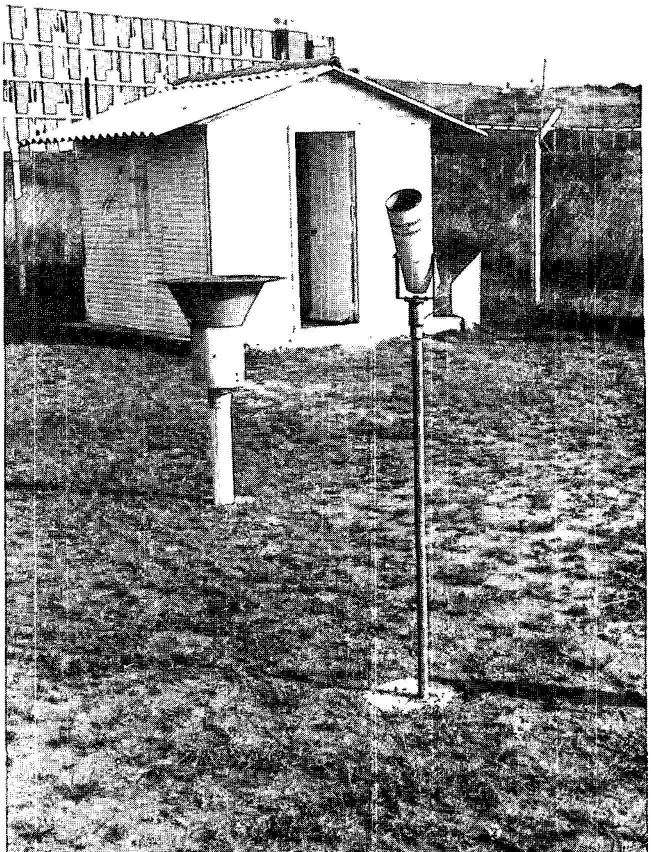

Figure 3
The rotating inclined gauge and the gauge fitted with the Nipher shield

Data Collection

Thirty-seven storms were selected for analysis. The values of these storms are given in Table 1. No meaningful differences could be traced between the data sets of the pit and shielded gauges and the catch average per storm was therefore accepted as the true values for the two gauges. The fact that no meaningful differences existed substantiated that the two gauges functioned properly and that no splash in or losses occurred. The catch average per storm was also used for the two standard height gauges.

Initially both the screened gauge and the inclined gauge presented problems. The Nipher screen gauge consistently showed lower readings than the perpendicular control gauges which is contrary to the theory discussed in the first part of the paper. This was seemingly caused by a turbulent eddying effect around the gauge which was placed deep down in the Nipher cone. The differences in level between the horizontal top side of the Nipher screen and the gauge orifice was apparently just large enough to cause slight eddying around the orifice, which resulted in a lower catch.

This was corrected by bringing the orifice and the screen top to the same level which excluded the turbulant eddying. Inspection of the inclined gauge during and after the first few storms suggested possible losses. Modifications were made to the catch container and it functioned well for the rest of the period. The rain gauges were read on a daily basis.

TABLE 1
DAILY RAINFALL IN mm AT SIX RAIN GAUGES

Storms	Exposed Gauges	Elevated Gauge	Protected Gauges	Inclined Gauge
1	50,4	48,0	56,4	66,9
2	9,0	8,5	10,4	14,4
3	26,2	24,7	30,8	40,0
4	30,1	29,6	32,0	35,5
5	15,0	14,0	16,5	19,0
6	9,6	9,3	11,0	13,7
7	12,3	11,9	14,0	16,0
8	7,4	7,3	9,0	14,6
9	23,4	22,3	26,3	42,0
10	15,0	14,6	16,8	20,9
11	7,2	7,1	8,1	15,7
12	15,2	15,0	16,5	28,0
13	25,5	24,3	25,7	35,5
14	9,7	9,3	10,5	20,0
15	9,4	9,0	10,5	16,5
16	7,8	7,2	8,0	16,0
17	16,0	15,0	16,2	20,6
18	27,5	27,0	29,0	32,0
19	10,5	10,3	11,9	18,5
20	5,0	4,4	5,8	7,8
21	3,1	2,8	3,3	5,1
22	7,0	6,8	7,2	9,6
23	7,4	7,0	8,0	11,8
24	33,6	32,1	36,4	50,3
25	4,8	4,5	5,2	8,0
26	5,1	4,5	5,6	8,4
27	17,2	16,8	18,5	25,8
28	9,2	9,0	10,4	17,0
29	12,9	12,7	13,6	16,9
30	11,5	11,1	12,8	17,0
31	21,6	21,0	23,4	28,8
32	4,8	4,7	5,0	7,0
33	15,9	15,4	17,4	21,9
34	6,2	6,0	6,8	9,0
35	13,5	13,0	15,1	21,1
36	3,9	3,6	4,2	5,5
37	4,9	4,4	5,7	8,0
T	594,8	548,0	656,0	873,8
A	16,1	14,8	17,7	23,6

Data Analysis

The daily rainfall data presented in Table 1 was tested to establish whether a meaningful difference existed between the values for the different gauges. An analysis of variance was carried out on the 37 showers registered and it indicated that the daily differences between the gauges were significant at a 5% level.

In comparing the total values for the 37 showers in Table 1 it becomes apparent that relatively large discrepancies are present. The total catch for the inclined gauge is, for example, significantly higher than any of the other totals. This pattern was consistent from shower to shower, but inconsistent in the sense that storms of approximately the same catch in the exposed gauges did not register the same values in the inclined gauge. This is explained by variations in the relation between the gauge aperture and the storm vector for the given storms.

A comparison between the inclined gauge values and the wind protected gauges, which is often accepted as control gauges or gauges with a higher degree of accuracy, reveals an average difference of 24,9%. Evidently the protection obtained in using shielded or pit gauges is just against turbulant eddies, updrafts and downdrafts in the micro-environment of the gauge orifice. If the rain in the meso-environment falls obliquely, shielded or pit gauges contribute little towards higher accuracy. Under these circumstances the effect of the aperture setting of the inclined rain gauge is more important.

In comparing the inclined gauge with the exposed gauge the differences are more striking, the average for the 37 showers being 31,9%. The effect of protection discussed in the previous paragraphs is obvious. The same pattern is obvious, however more intense, when the inclined gauge and the elevated gauge is compared. Further illustration of the effect of wind protection lies in a comparison between the data of protected and exposed gauges. The protected gauges yielded on average a 9,3% higher catch with relatively small deviations from the average.

The relation between the gauges was then analysed using

TABLE 2
LINEAR REGRESSION IN mm PER STORM:
STANDARD GAUGE AGAINST ELEVATED GAUGE;
STANDARD GAUGE AGAINST PROTECTED GAUGE;
STANDARD GAUGE AGAINST INCLINED GAUGE;
PROTECTED GAUGE AGAINST INCLINED GAUGE

Equation	R^2
$Eg = 0{,}96\ Sg - 0{,}04$	0,99
$Pg = 1{,}09\ Sg + 0{,}02$	0,99
$Ig = 1{,}29\ Sg + 2{,}66$	0,95
$Ig = 1{,}18\ Pg + 2{,}53$	0,95

linear least squared regressions and coefficients of determination. In three cases the exposed rain gauges set up at the standard height of 1,2 m was accepted as the independent variable with the elevated, protected and inclined gauges respectively the dependent variables. In a further calculation the protected gauge values as independent variables were analysed against the inclined gauge values as the dependent variables. The results are shown in Table 2.

From Table 2 it is obvious that the correlation coefficients of the data sets are high, indicating that a large percentage of variance in the dependent variable is explained by the independent variable. From this it follows that the dependent variable values could be assessed with relative accuracy from a knowledge of the independent variable alone. This is of particular interest in the third equation in Table 2 depicting the relation between the exposed and inclined gauges. Exposed gauge values are commonly used erroneously instead of inclined gauge values. The limitations of a fixed tilt inherent in this particular model must however be conceded.

To overcome this, a more versatile model described by Hamilton (1954) was tested on a sample of 15 storms in Table 1. The method involves the correction of vertical gauge records to depict tilted gauge records. Fifteen exposed vertical gauge values were subsequently corrected and the computed values compared with the measured values in column 5 of Table 1. The difference between the computed values and measured inclined values did not exceed 10% for any particular shower. The model quoted by Hamilton (1954) is stated as follows:

$$r = R + R \tan a \tan i \cos (B - w)$$

where

r = true rainfall sample;
R = sample from vertical gauge;
a = gradient of slope being sampled;
i = angle of inclination of rain (from vertical);
B = aspect of slope being sampled;
w = average storm direction.

The above model combines the different vectorial components in order to obtain the resultant vector for a particular shower. This can be extended to any number of showers leading to the conception of a resultant vector for a rain season which makes it possible to calculate the amount of rain falling on the ground, regardless of the gradient of the slope or the inclination of the rain. Thus, either vertical or tilted gauges may be used to sample rainfall, on condition that vertical gauge values are corrected.

Uncorrected values are often used, even in research, with the end results to a large extent distorted. Records, once collected and published, often gain an aura of respectability and precision that is beyond tolerances that can legitimately be assigned to them. Rain gauge records should not be used without considering the effects of potential errors because errors become more important as one proceeds from empirical studies, in which the precipitation value may be only an index, to more basic studies which require absolute values. An error of 5 or 10% may be relatively unimportant in data from a rain gauge that is part of a climatological network with the purpose to provide index values for a general climatic characterization of the area represented by the gauge. However, a 5 or 10% error may be very important in a hydrological network, whose purpose it is to provide quantitative precipitation input to an intensive hydrologic investigation. Then, the rain gauge error may be larger than other components being studied in the hydrologic cycle (Neff, 1977).

Conclusion

The largest source of error connected to rain gauge readings lies in the assumption that they represent the actual precipitation at the site. Rain gauge records must be used with care and with consideration of the potential errors which could be accentuated in empirical studies. This does not make the present rainfall records useless or exclude the use of vertical rain gauges. If the components of rainfall are known, rain vectors for storms of either uniform or varying direction and inclination can be determined and can be used to compute true rainfall from a vertical gauge.

References

BISWAS, A.K. (1967) Development of rain gauges. *Am. Soc. Civ. Eng.* 93 (IR 3) 99–124.

COURT, A. (1960) Reliability of hourly precipitation data. *J. geophys. Res.* 65 (12) 4017–4023.

HAMILTON, E.L. (1954) Rainfall sampling on rugged terrain. *U.S. Dep. Agric. Tech. Bull.* 1096. 41 pp.

NEFF, E.L. (1977) How much rain does a rain gauge gage? *J. Hydrol.* 35 (3/4) 213–220.

RODDA, J.C., DOWNING, R.A., LAW, F.M. (1976) Systematic Hydrology, London: Butterworth's, 25–83.

SHARON, D., YISRAELI, A. and LAVEE, H. (1976) *A model for the distribution of the effective rainfall incident on slopes and it's application at the Sdeh Boqer experimental watershed.* Hebrew University of Jerusalem, technical paper no. 26, 30 pp.

VAN HEERDEN, W.M. (1961) The direction of rain and its measurement *S. Afr. J. Agric. Sci.* 4 (1) 51–61.

WARD, R.C. (1975) Principles of Hydrology, 2nd Ed., London: McGraw Hill, 16–49.