

The slanting hole raingauge proposed for hillslope hydrology

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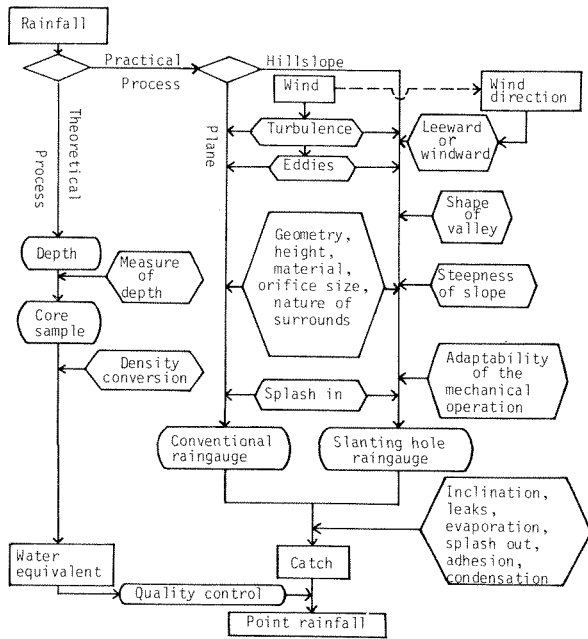
ABSTRACT To investigate storm characteristics in typhoon areas, the correct location of the most suitable type of raingauge on a hillslope is the main method of improving the validity of hydrological projects in watershed engineering. To account for variations due to topography, aspect, wind speed and other factors, experiments of latin square design, three randomized complete block experiments and other experiments were performed in Japan and Taiwan. From a statistical analysis of the data from experiments using four kinds of raingauge: tilted, slanting hole, Hamilton's vector, and conventional, the slanting hole raingauge is proposed as the most suitable for installation on hillslopes. Detailed procedures showing how to compute the dimensions of the orifice, how to set up the gauge, and how to check the validity of its operation, are also given.

Propositions pour un pluviomètre à ouverture inclinée pour l'hydrologie des bassins versants à flanc de coteau

RESUME Implanter correctement un pluviomètre de conception parfaitement appropriée sur les pentes des collines est la meilleure façon d'améliorer la validité des études hydrologiques pour les aménagements des bassins, dans le cas d'observations des précipitations provoquées par les typhons. Pour prendre en compte les variations résultant de la topographie des bassins, de la vitesses du vent et d'autres facteurs, des expérimentations sur la base de la méthode du carré Latin, sur des blocs avec répartition au hasard des appareils et d'autres essais ont été effectués au Japon et à Taiwan. Se basant sur l'analyse statistique des données de ces recherches comparant quatre types d'appareils: à auget basculeur, à orifice incliné, le vecto-pluviomètre d'Hamilton et le pluviomètre conventionnel, on propose d'adopter le pluviomètre à orifice incliné comme appareil standard pour les études hydrologiques sur les pentes des collines. On donne également les méthodes détaillées pour calculer les dimensions de l'orifice mettre en place l'appareil et vérifier si l'emploi de ce pluviomètre est effectué correctement.

INTRODUCTION

In assessing point rainfall the usual procedure is to ascribe to each sample a certain representativity of measurements on hillslopes depends on the type of gauge, steepness of slope, aspect, shape of valley, incidence of wind, and elevation. Figure 1 shows the flow chart of a point rainfall on the level and on a hillslope. The conventional raingauge and slanting-hole raingauge in practical process correspond to the core sample in theoretical process for the plane and hillslope respectively.



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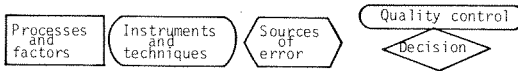


FIG.1 Flow chart of point rainfall (modified from Edwards, 1969; and Liang, 1979).

As regards the conventional raingauge, the most common errors result from evaporation, adhesion, colour, inclination of the gauge, splash, wind, faulty technique in measuring the catch, and physical damage to the gauge. Kurtyka (1953) estimated the errors as follows:

Evaporation	-1.0%
Adhesion	-0.5%
Colour	-0.5%
Inclination	-0.5%
Splash	+1.0%
Wind	-5.0 ~ -80.0%

Most errors regarding conventional raingauges located on the level

result from wind.

This paper considers the results obtained from a series of experiments using different types of raingauges in different situations. The problem of selecting the right type of raingauge for hillslopes, reliability of the slanting hole raingauge, and sources of error in results from the various gauges are also considered.

EXPERIMENTAL METHOD

Type of raingauge and the measure of depth

Four types of raingauges installed with their receivers at a height of 60 cm above ground are considered. Figure 2 shows these gauges: the Hamilton's vector, conventional, tilted, and slanting hole.

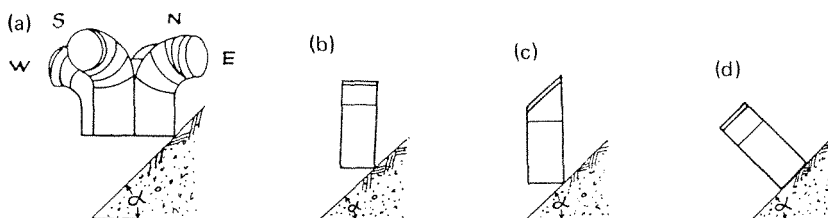


FIG.2 (a) Hamilton's vector raingauge: $R = R_C + R_C \tan \alpha \tan i \cos \delta$. (b) conventional raingauge: $R = R_C$. (c) slanting hole raingauge: $R = R_S$. (d) tilted raingauge: $R = R_T \sec \alpha$.

According to Fourcade (quoted from Hamilton, 1954) the depth R for Hamilton's vector is computed from (1).

$$R = R_C + R_C \tan \alpha \tan i \cos \delta \quad (1)$$

where R_C = the depth obtained from a conventional raingauge; α = slope angle; i = angle of inclination of rainfall (angle between the direction of rainfall and the vertical),

$$\tan i = [(N - S)^2 + (E - W)^2]^{1/2} / R_C \quad (2)$$

where N , S , W , E are the depths obtained from the north-facing, south-facing, west-facing, and east-facing components of the Hamilton's vector raingauge respectively; and δ = the angle between ω and the direction of greatest slope, where

$$\omega = \tan^{-1} [(E - W) / (N - S)] \quad (3)$$

Layout of experimental sites

Experiment 1 The four kinds of raingauge were installed on the slopes of a V-shaped valley in the Kasuya Experimental Forest, Kyushu University, Japan, between March 1968 and December 1969 (Chiang, 1970).

The gauges were arranged in a latin square design on both the south-west and northeast slopes (Fig.3).

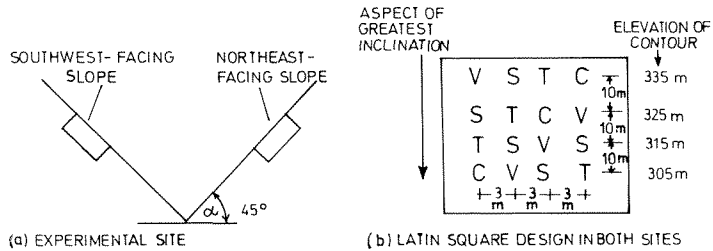


FIG.3 Layout of experiment 1. V, S, T, C respectively denote a Hamilton's vector, slanting hole, tilted and conventional raingauges.

Experiment 2 Four kinds of raingauges were installed on the same site as experiment 1 and arranged in a randomized complete block design (Fig.4) from March 1969 to December 1971 (Chiang, 1972a).

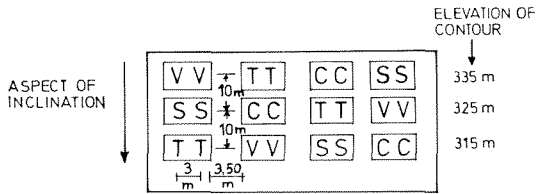


FIG.4 Arrangement of raingauges at both sites used in experiment 2.

Experiment 3 Three kinds of raingauges were installed on two different slopes according to the randomized complete block design (Fig.5) at Huei San Experimental Forest, National Chung Hsing University, Taiwan, China, from July 1971 to July 1972.

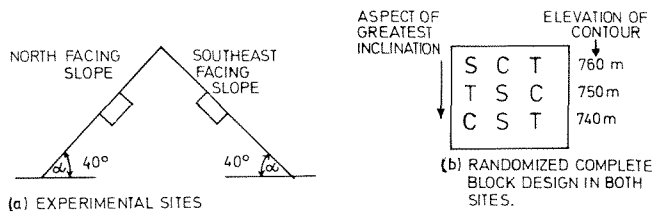


FIG.5 Layout of experiment 3.

Experiment 4 One recording slanting hole raingauge was installed at a height of 325 m on both slopes of the V shaped valley used for experiment 1 from May 1972 to August 1972 (Chiang, 1973a).

Experiment 5 Windshields were arranged according to the random-

ized complete block design at the site used for experiment 3 as shown in Fig.6 from August 1973 to July 1974.

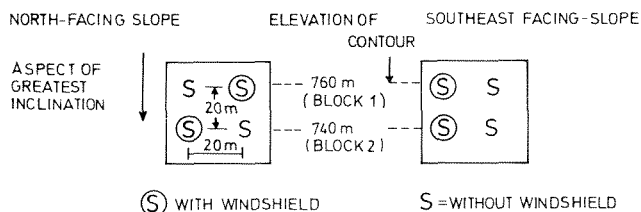


FIG.6 Arrangement of raingauges on each site of experiment 5.

Experiment 6 One recording conventional rain gauge was installed on each slope of the sites used for experiment 4 from March 1970 to December 1971.

Experiment 7 Three sets of Hamilton's vector rain gauges were installed on the north-facing slope of the Huei San Experimental Forest, National Chung Hsing University, Taiwan, China, at an altitude of 820 m from April 1973 to October 1973 (Chiang, 1973b).

RESULTS, DISCUSSIONS, AND CONCLUSIONS

Table 1 shows the results obtained from experiments 1, 2, 3 and 5. Statistical analyses were performed storm by storm. (*) Indicates the depth measured by the same type of rain gauge under the influence of various erratic sources reaches the 5% significance level; (**) indicates it has reached the 1% level of significance. The higher the score, the poorer the accuracy of the rain gauge type. Out of 20 storms in experiment 1, Hamilton's vector rain gauge scores 6* and 5**; the conventional rain gauge scores 2* and 2**; the tilted rain gauge, 1* and 1**; and the slanting hole rain gauge scores 1* only. Certainly Hamilton's vector rain gauge dropped behind the rest, and therefore, will no longer be considered in experiment 2. In experiments 2 and 3, the conventional rain gauge showed many faults, especially under strong wind conditions. The tilted rain gauge is inferior to the slanting hole rain gauge under low wind velocities, say, below 4 m s^{-1} . The results from these three experiments lead to the conclusion that the slanting hole rain gauge is the most suitable for hillslope conditions. More evidence to substantiate this conclusion is given in the next two paragraphs.

A windshield does not improve the accuracy of the slanting hole rain gauge as can be seen from the results of experiment 5 in Table 1. Therefore, it is not necessary to install a windshield in front of a slanting hole rain gauge on a hillslope when the wind speed is not more than 6 m s^{-1} (Chiang, 1974).

Figure 7 shows that topography, wind speed and storm characteristics do not affect the accuracy of the slanting hole rain gauge in experiment 4.

Experiment 6 shows that the conventional rain gauge is affected by

TABLE 1 Statistical analyses for experiments 1, 2, 3 and 5

Type of rain gauge	Wind velocity (m s ⁻¹)	Experiment			
		1 ⁺	2 [§]	3 [§]	5 [§]
HAMILTON'S VECTOR	Unknown	0	-	-	-
	0.0~2.0	3*4**/11	-	-	-
	4.1~6.0	1*1**/4	-	-	-
	>6.0	0/1			
CONVENTIONAL	Unknown	0	5**/10	0	-
	0.0~2.0	0/4	6*6*/34	6*7**/25	-
	2.1~4.0	0/11	2*11**/16	1**/4	-
	4.1~6.0	1*2**/4	3**/4	0	-
	>6.0	1*/1	2**/2	0	-
TILTED	Unknown	0	1*/10	0	-
	0.0~2.0	0/4	3*1**/34	3*/25	-
	2.1~4.0	1**/11	1*3**/16	0/4	-
	4.1~6.0	1*/4	0/4	0	-
	>6.0	0/1	1*1**/2	0	-
SLANTING HOLE	Unknown	0	1*/10	0	0
	0.0~2.0	0/4	2*/34	1*/25	0/27
	2.1~4.0	0/11	1*/16	0/4	0/7
	4.1~6.0	1*/4	0/4	0	0/1
	>6.0	0/1	1*1**/2	0	0

+ Latin square design.

§ Randomized complete block design.

* Denotes 5% significance level and ** denotes 1% significance level for rainfalls collected by the same type of rain gauge.

changes in topography and wind speed. The results from conventional rain gauges, located on slopes with different aspects differ depending on the wind speed (Fig.8). The stronger the wind, the larger the difference.

The weakness of the Hamilton's vector rain gauge can be derived from the inaccuracy of the Fourcade formula. The ω values obtained by equation (3) are counted clockwise from the base line of the northern direction storm by storm. The standard error of the mean (Sω) of ω among three rain gauges located along the same contour on the same slope increases with increased wind speed as shown in Fig.9.

Since the slanting hole rain gauge works so well it is necessary to know how the rim of the receiver can be computed and how to set up this type of rain gauge. Three coordinates (S_i, ΔH_i), (L_i, ΔH_i) and (L_i, S_i) are assigned as shown in Fig.10. Equation (4) expresses the relationship between these three coordinates:

$$\Delta H_{max} = D \tan \alpha$$

$$d_i = R - \Delta H_i / \tan \alpha$$

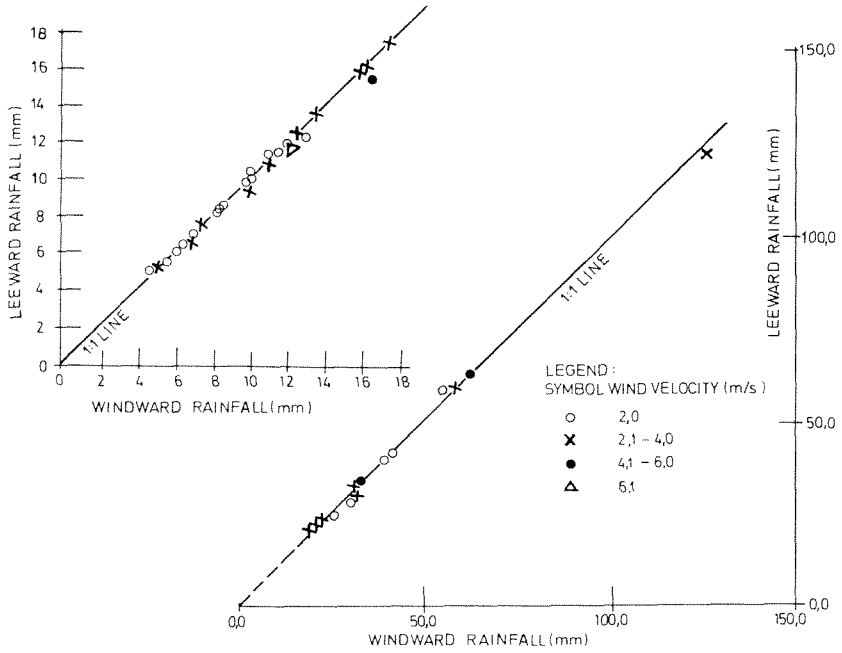


FIG.7 Data from the slanting hole rain gauge show consistency under various wind velocities, storm characteristics and both leeward and windward locations.

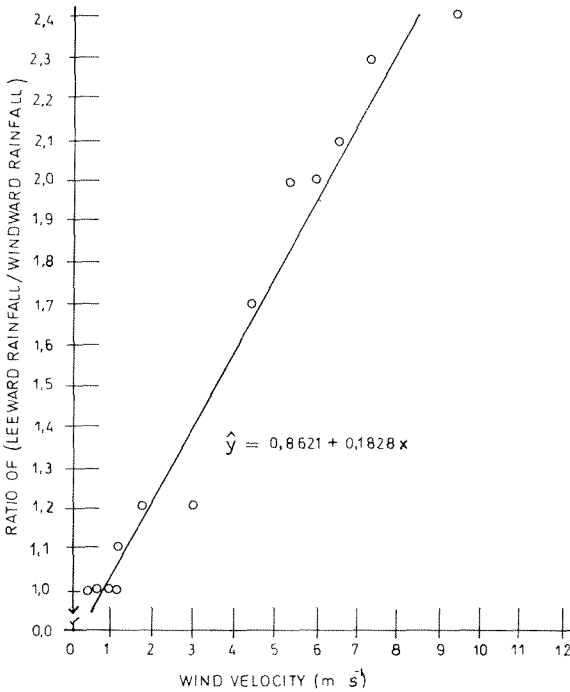


FIG.8 Linear regression of leeward rainfall/windward rainfall and wind velocity (after Chiang, 1972b).

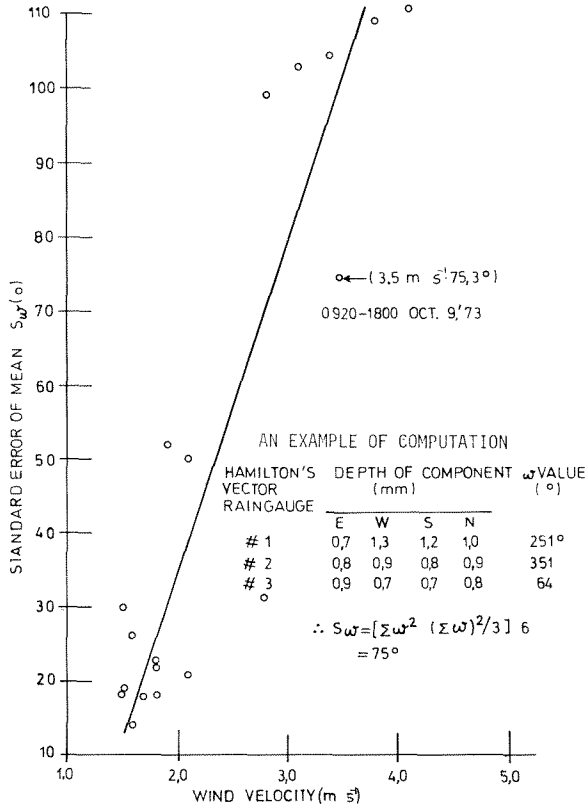


FIG.9 Relationship between errors using three Hamilton's vector raingauges and wind velocity.

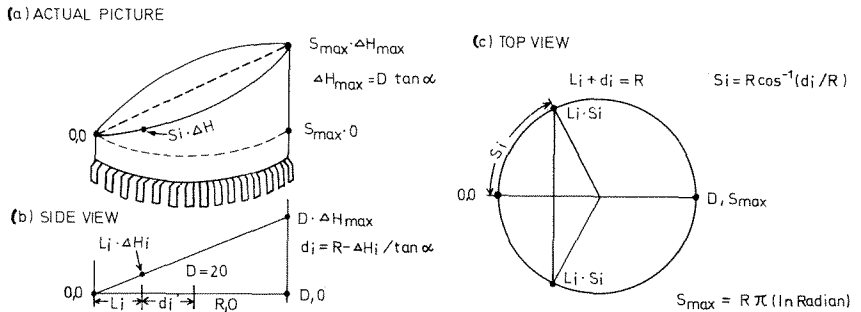


FIG.10 The slanting hole rain gauge (after Liang, 1977).

$$S_i = R \cos^{-1}(d_i / R)$$

$$S_{\max} = R \pi \text{ (radians)} \tag{4}$$

where D and R are the diameter and radius of the conventional rain gauge respectively, α is the angle of slope in degrees, and d_i is a transient parameter. The calculator and the computer programs for computing points $(S_i, \Delta H_i)$ may be obtained from Liang (1977). Once the points $(S_i, \Delta H_i)$ are obtained, the procedure shown in Fig.11 is followed to set up the slanting hole rain gauge. The mechanical

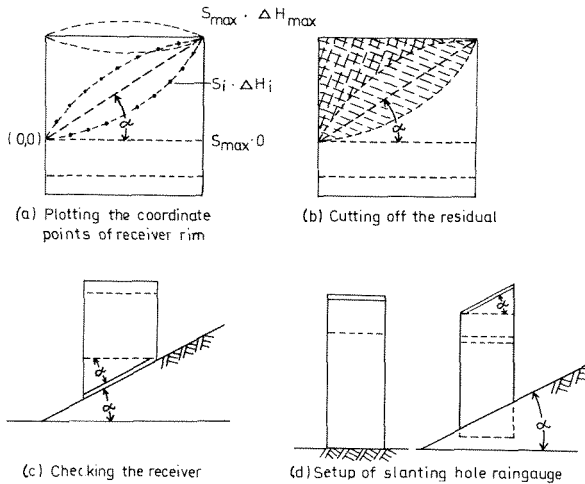


FIG. 11 Installation of slanting hole raingauge (after Liang, 1979).

operation of recording rainfalls using slanting hole gauges is not changed at all, and is reliable.

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