Appendices

Appendix A Index of symbols

Symbol	Definition
A	drainage area (source area)
b	channel width
g	gravitational acceleration
I_R	effective rainfall intensity
k	surface roughness coefficient
k_p	dimensionless coefficient on runoff peak generation
m	power of S_c in critical discharge equation
n	Manning's resistance coefficient
P_i	daily rainfall on the i-th day before the date of observation
Q	discharge
Q_{cr}	critical discharge for bedload transport
Q_s	spring discharge
Q_p	peak discharge
Q_p/A	peak specific discharge
R_1	maximum 1-hour rainfall
R_4	maximum 4-hour rainfall
$(R_4)_{cr}$	critical 4-hour rainfall for bedload transport
R_{24}	maximum 24-hour rainfall
R_{c4}	critical 4-hour rainfall for runoff generation
R_{cT}	critical T-hour rainfall for runoff generation
R_T	maximum T-hour rainfall

R_{total} total rainfall of an event

S_c local channel gradient ($S_c = \tan\theta_c$)

S_h local head slope ($S_h = \tan\theta_h$)

T duration of rainfall

Y_a annual bedload yield

Y_t total bedload yield

Y_w bedload yield in winter

α_p ratio of peak-discharge increment to drainage-area increment

α_s ratio of spring-discharge increment to drainage-area increment

β_p critical drainage area for peak-runoff generation

β_s critical drainage area for spring-runoff generation

γ constant on critical discharge in observed flow condition

γ_L constant on critical discharge in laminar-flow condition

γ_T constant on critical discharge in turbulent-flow condition

ν kinematic viscosity

ρ_w density of water

θ_c local channel angle

θ_h local head-slope angle

τ_{cr} critical shear stress for bedload transport

Appendix B Calculation of return period

Return period of 4-hour rainfall R_4 was estimated from the return periods of daily and hourly rainfalls at the 'Utsunomiya' observatory, JMA, with a method for estimating the intensity of long-duration rainfall (Iwai and Ishiguro, 1970; pp. 174-177). Equations in this method were described as follows:

$$R_T = \frac{TR_{24}}{24} \times \frac{c+24}{c+T} \quad \text{(B1)}$$

$$c = \frac{24-\beta_1}{\beta_1 - 1} \quad \text{(B2)}$$

$$\beta_1 = \frac{24R_1}{R_{24}} \quad \text{(B3)}$$

where R_T is T-hour rainfall, R_1 is hourly rainfall, and R_{24} is daily rainfall.

In the case of 10-year return period estimated from Chow's method (Chow, 1964), the hourly rainfall R_1 is 68 mm, and daily rainfall R_{24} is 151 mm (Table 1). Substitution of these hourly and daily rainfalls into Equations (B1), (B2) and (B3) with T = 4 h yields R_4 = 119 mm. This value is considered as 4-hour rainfall with 10-year return period. In a similar manner, the values of R_4 for each return period can be calculated from a dataset of hourly and daily rainfalls with a known return period (Figure B1). The estimated return period is consistent with the observed return period in the investigated area.

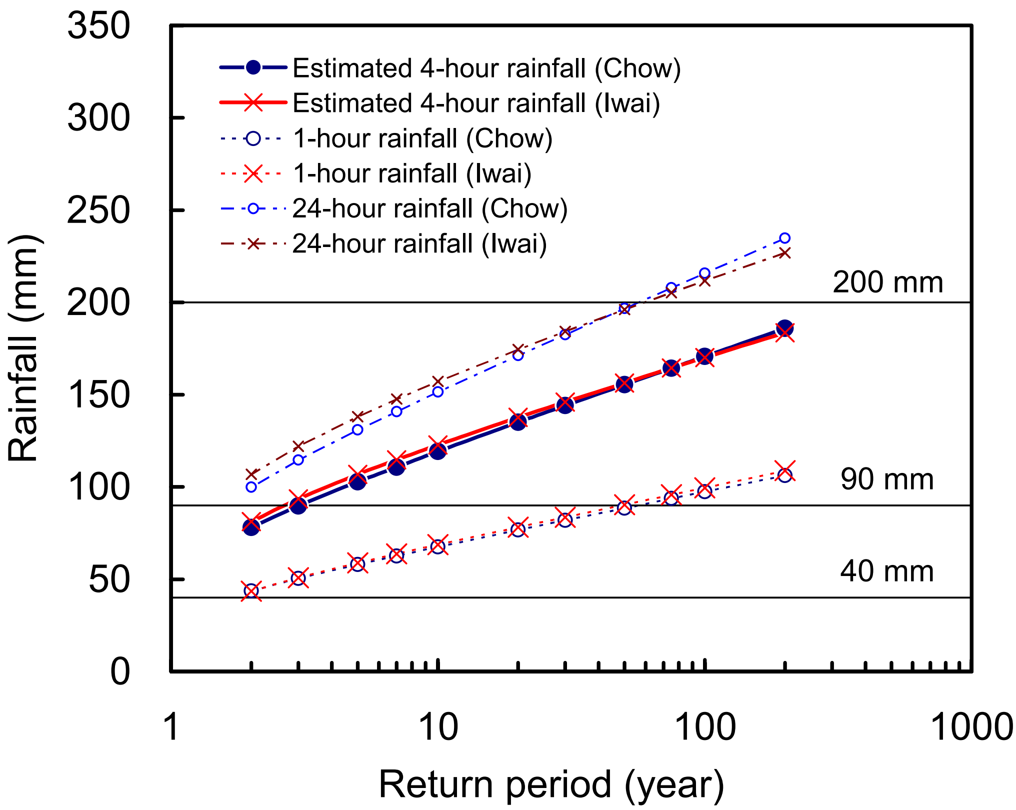

Figure B1: Estimated return period of 4-hour rainfall

Return period of 1-hour and 24-hour rainfall was calculated with the extreme data at 'Utsunomiya' meteorological observatory, JMA (Table 1). 'Chow' and 'Iwai' indicate the methodology for calculating the return period. 4-hour rainfall of each return period was calculated from the equations for estimating rainfall intensity suggested by Iwai and Ishiguro (1970).