Runoff and flood characteristics in some humid tropical regions

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ABSTRACT In the humid tropical regions of Asia the staple diet is rice. To increase rice production, it is necessary to establish irrigation and drainage systems and manage these effectively. The study on runoff and flood characteristics is of vital importance in Asia. This paper first discusses annual precipitation, the spatial distribution of rainfall, and the return period of heavy rainfall. Next, annual runoff ratios, flood runoff ratios and other runoff parameters are listed. They characterize the humid tropical region from the hydrological viewpoint. Finally, a flash flood based on humid tropical conditions is considered. This caused serious devastation in a limited area with heavy debris flow.

Caractéristiques des écoulements et des crues de certaines régions tropicales humides
RESUME Dans les régions tropicales humides d'Asie, le principal aliment de la population est le riz. En vue d'augmenter la production de riz, il est indispensable de mettre en œuvre des systèmes d'irrigation et de drainage. L'étude des caractéristiques relatives à l'écoulement et aux crues est d'une importance vitale en Asie. Ce rapport traite tout d'abord des précipitations annuelles, de la répartition spatiale des précipitations et des périodes de retour des fortes averse. Les données concernant les averse révèlent plusieurs caractéristiques remarquables. Les valeurs de l'écoulement annuel, les caractéristiques des crues annuelles ainsi que d'autres paramètres qui leurs sont relatifs sont par la suite énumérés. Ils caractérisent les régions tropicales humides du point de vue hydrologique. Une crue subite est prise en considération en se basant sur les conditions tropicales humides, à la fin de ce rapport. Elle est la cause de graves désastres dans des zones limitées et charrie des débris divers en grande quantité.

INTRODUCTION

Floods are one of the most disastrous phenomena occurring all over the world. Many people may be washed away in a second, and many properties can be damaged by a flood. A flood is a fatal obstacle to social progress both in developing and developed countries. Its
characteristics must be defined from social and hydrological viewpoints.

Most of the developing countries, including Japan, are located in humid tropical regions where a flood occurs every year. Strange as it may sound, years ago a flood was not considered a disaster; people live on rice in southeast and east Asia, and rice needs plenty of water as well as a high temperature. People planted flood-resistant rice although it was not high productive. A moderate flood was preferable to a drought. Nowadays all countries desire to develop their economies as quickly as possible. In order to increase rice production, highly productive rice which is intolerant of flooding is now planted and costly irrigation and drainage facilities have been constructed in humid tropical regions. These facilities are easily damaged by flooding. Under such conditions a flood is very disastrous to agriculture.

The problem of urbanization is similar to agriculture. In some countries a water festival is held during the flooding period in rural communities. But a flood is called harmful when living conditions are affected by flooding in the highly urbanized communities. All countries are now trying to develop urban communities. They have constructed roads, bridges, factories, hydropower plants with much effort, and have made other investments in the basins. In spite of eager activities for development, flood damage increases year by year especially in humid tropical regions.

The author introduces runoff and flood characteristics observed in some humid tropical regions like Japan. He first discusses the variation of rainfall, and secondly runoff ratio. In addition to this the vulnerability to flash flooding is also mentioned in this report.

RAINFALL

A flood in a humid tropical region displays characteristics somewhat different from those in semiarid or temperate zones. Although snow-melt floods are common in Europe and the northern part of North America, rainfall is the main cause of large floods in southeast and east Asia. When a monsoon blows from the sea or a typhoon (a tropical cyclone is called a typhoon in southeast and east Asia) passes over or near to the region, it rains heavily everywhere. Other meteorological disturbances such as a front and a thunder storm also produce heavy rainfall.

Japan is one of the humid tropical countries though it is located in the high latitude. It is covered by tropical Pacific air masses in summer. Therefore, it is hot and humid during the summer season. There are three wet seasons in Japan: two are warm rainy seasons, namely June-July and September-early October.

Annual precipitation

The annual precipitation is of course bigger in the humid tropical regions than in other regions. It is 1800 mm in Manila, 1600 mm in Calcutta, 1500 mm in Bangkok and Tokyo. It is affected by local conditions. On the Pacific side of the mountain range of Japan, it
is much more, namely 4200 mm in Owase and 2600 mm in Miyazaki. The community which is located in a high precipitation area is well accustomed to floods. A simple key of foreseeing rainfall disasters is some fraction of the annual precipitation. Roughly speaking, when 1/10 of the annual precipitation is observed in a storm, a rainfall disaster occurs in a rural area, and when 1/20 is observed, a rainfall disaster occurs in an urban area in Japan. Every country should find a similar threshold in its own area to make disasters predictable.

Spatial distribution

As the tropical rainfall is produced by convective clouds, rainfall in a humid tropical region generally has a random distribution. The correlation of daily rainfalls between two stations is almost always low, as is shown in Fig. 1, (Overseas Technical Cooperation Agency, 1970). When a monsoon lasts for a long time, or a typhoon comes, a lot of rain clouds are stimulated everywhere and continuous heavy rainfall is induced over a wide area. In this case a big flood occurs. In addition to a typhoon, a frontal activity often causes a flood or a flash flood in Japan. Along the front over Japan during the rainy season, a small but strong convergence occasionally appears. It brings forth local heavy rainfall. Arao (1982) reported the spatial distribution of the 24 h rainfall of 23 July 1982 in Nagasaki in the western part of Japan, where 299 persons were swept away (Fig. 2). The long axis of 200 mm of rainfall is only 80 km long. The maximum 24 h rainfall is 608.5 mm in this case.

FIG. 1 The correlation of daily rainfall between two stations in the Pampanga River basin, more than 1.5" in either station.
Rainfall probability

A typhoon has a certain probability of occurrence, therefore rainfall caused by a typhoon is also probabilistic. Two or more strong typhoons may strike in a year (two typhoons in Tokyo in 1982), while no typhoon may come in a few decades. The discharge may be adequate to design structures, but it is easily affected by human activities as will be mentioned later. Therefore, the rainfall may be taken as a good probability parameter. Kinosita (1980) reported examples of return periods of rainfall used for disaster prevention in Japan. Return periods of 100 ~ 200 years are used for river improvement works for class A rivers, 1 ~ 10 years for drainage systems of roads, and 5 ~ 10 years for sewerage systems.

The rainfall of some return periods is also dependent upon the period of statistics at a certain site. In other words, the probability of rainfall is changing with time. Figure 3 shows how many times daily rainfalls greater than the rainfall of the 100-year return period occurred during the 31 years between 1950 and 1980, where the rainfall of the 100-year return period is determined by the set of annual maximum daily rainfalls during the period 1900-1949 at the
same site (Kinosita, 1982a,b). At some sites, rainfalls greater than the rainfall of the 100-year return period occurred four times in the 31 years. This means that probability and the daily rainfall increases of the latest years should be considered.

**RUNOFF CHARACTERISTICS**

What percentage of rainwater runs off into the river in humid tropical regions? Consideration should be given to the period during which the runoff process occurs. A year is an important period for the hydrological cycle, while a storm period or the time of concentration is also meaningful. Runoff characteristics, for instance a runoff ratio, are discussed in this section for flood damage mitigation and water resources development.

**Annual runoff**

The annual runoff in Japan is analysed by comparing it with the annual precipitation (Public Works Research Institute, 1969) as illustrated in Fig.4, where the annual precipitation is in mm on the abscissa and the annual runoff is in mm on the ordinate. Each point corresponds to the relation in a year in a certain drainage basin. All points must lie on the 45° lines when all the rainwater runs off to the river. There are some points above the 45° line due to inadequate observations of snow in the northern mountain basins in winter. Most of the points are plotted within a zone of about 500 mm below the 45° line. Therefore, the annual loss, which is the difference between the annual precipitation and the annual runoff may be about 500 mm on average. The annual loss is influenced by geology, climate and other factors. For instance, in some basins where porous pyrocrastic rocks are predominant, it is almost 1000 mm, while in a neighbouring basin it is nearly equal to zero due to the groundwater supply. As a climatic factor, evapotranspiration is estimated at
600 to 700 mm a year by formulae using air temperature. It might be said that the loss of rainfall is rather small in humid regions because of high atmospheric humidity.

Flood runoff ratio
A flood runoff ratio is the ratio of the volume of the flood water to the volume of the rainwater during the flood period. The flood water in this interpretation includes all components of runoff, namely overland flow, interflow, and baseflow during the flood. Depression storage, groundwater recharge and other components of basin storage are not included. The runoff ratios obtained in recent floods in Japan observed by the Ministry of Construction (1981 & 1982) are listed in Table 1 where all data except Kurihashi were recorded at multipurpose reservoirs near Tokyo. The basin is covered with forest and rice fields. The ratio is 0.7 to 0.8 when the total rainfall is about 200 mm. The major portion of rainwater turns to river discharge if the rainfall is heavy. This trend was proved by a runoff experiment using a rainfall simulator at the National Research Centre for Disaster Prevention (Fig.6). According to the data measured on the experimental plot of 1000 m², Kinosita & Nakane (1977) found that the loss decreased with the increase of rainfall over the critical rainfall. Therefore it appears that the runoff ratio increases considerably with increasing rainfall.

The main concern of hydrologists in humid tropical regions is the determination of the distribution of runoff with time from the unit of rainfall as can be obtained by the unit hydrograph method, because the loss is generally minor during flood periods; though the estimation of effective rainfall is of prime concern in semiarid and temperate zones. All the conceptual models developed in Japan try to estimate the hydrographs from rainfall (Kinosita, 1981).

<table>
<thead>
<tr>
<th>Drainage area (km²)</th>
<th>August, 1981. Ty8115</th>
<th>August, 1982. Ty8210</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rₜ (mm)</td>
<td>Qₜ (mm)</td>
</tr>
<tr>
<td>Sonohara</td>
<td>493.9</td>
<td>211.5</td>
</tr>
<tr>
<td>Shimokubo</td>
<td>322.9</td>
<td>243.7</td>
</tr>
<tr>
<td>Kusaki</td>
<td>254.0</td>
<td>388.0</td>
</tr>
<tr>
<td>Ikari</td>
<td>271.2</td>
<td>329.7</td>
</tr>
<tr>
<td>Kawamata</td>
<td>179.4</td>
<td>366.7</td>
</tr>
<tr>
<td>Futase</td>
<td>170.0</td>
<td>273.7</td>
</tr>
<tr>
<td>Kurihashi</td>
<td>8588.0</td>
<td>213.2</td>
</tr>
</tbody>
</table>
Runoff and flood characteristics

The runoff coefficient is characterized as a parameter of the rational formula

\[ Q = f r A/3.6 \]

Where \( Q \) is the discharge \( (m^3s^{-1}) \), \( f \) is the runoff coefficient; \( r \) is the rainfall intensity within the time of concentration \( (mm\ h^{-1}) \), \( A \) is the drainage area \( (km^2) \). The formula is generally applied to estimate the peak discharge for the design of a flood channel. The time of concentration is assumed to be twice the difference between the peak time of the rainfall and that of the runoff. The runoff coefficient is not the same as the runoff ratio but is also dependent upon the rainfall amount and other geological and climatic parameters. The examples of the Tone River in Japan and the Pampanga River in the Philippines obtained by Kinosita (1982) are plotted in Fig.7. Both river basins have almost the same annual rainfall and vegetal cover. The runoff coefficient is 0.6 \( \sim \) 0.8 for the Tone River, and 0.2 \( \sim \) 0.3 for the Pampanga River. This difference may be caused by the retardation effect of the basin. Depression storage in foothills, swamp storage and other natural conditions may greatly reduce the peak discharge of a flood. One comment must be added concerning the
time of concentration. There are two or three peaks in a hyetograph. It is difficult to identify the significant peak of rainfall with regard to the flood peak. Some ambiguity cannot be avoided in deciding the time of concentration in the case of two or more rainfall peaks. Some errors might be included in the plots shown in Fig.7. Agricultural developments such as swamp reclamation, construction of embankments, and sophisticated irrigation and drainage systems, induce an increase in the runoff coefficient as well as a decrease in the time of concentration. In some cases flood prevention measures might increase the flood discharge.

FLASH FLOOD

One particular flood in the humid tropical regions is the flash flood
Runoff and flood characteristics

(Kinosita, 1974). It occurs within a limited area immediately after heavy rainfalls. It takes place unexpectedly and causes serious damage.

Kelang River flows through Kuala Lumpur in Malaysia. All the tributaries join together in the city. Therefore a flash flood often occurs on the Kelang River at the centre of the city. The Government of Malaysia, Drainage and Irrigation Department developed a good procedure for forecasting a flash flood, using the flood warning table prepared for easily forecasting the water level by combining three parameters: rainfall over the drainage area measured in the last 24 h, rainfall in the last hour, and the duration of the storm in hours.

In Japan a flash flood is produced by the heavy rainfall of a typhoon or a frontal activity. As illustrated in Fig. 2, there was a big flash flood in Nagasaki Prefecture in July 1982: 299 lives were lost in one night. No streamgauging station was installed there. The specific flood discharge was estimated to be 42 m$^3$s$^{-1}$km$^{-2}$ from flood marks by the Nakazima River (Nakane, 1983). This value seems unlikely, but it is one of the characteristics of humid tropical regions.

CONCLUSION

The author discussed runoff and flood characteristics in Japan and other humid tropical regions. The results reported in this paper are useful for preventing flood disasters in agriculture, especially rice production, as well as in industrial and urban areas.

REFERENCES


