Watershed Environment Impact from Sediment Related Disasters Caused by Heavy Rainfall Under Climatic Change in Taiwan

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Abstract

Serious natural disasters such as landslide, debris flow, flooding and sediment related disasters were induced by the Morakot typhoon on August 8, 2009 with rainfall amount of 2,900mm within continuous 3 days in Kao-Ping area. This research mainly concentrates on applying field investigations integrated with GPS/GIS/RS techniques to investigate the characteristics and mechanism of sediment related disasters occurred at Kao-ping watershed. A study on the indicator of hydrologic alteration (IHA) influenced by this heavy rainfall event brought by Morakot become an important issue concerned by the government in Taiwan. This research was conducted by using HEC-RAS program developed from American Army Corps Engineering, USA. The change of hydrological environment resulted from this extremely heavy rainfall during the past 10 years should be required as an important data for this study. All results indicate that the concentration of sediment for the Kao-ping watershed was increased 25~33% during the rainfall season and 5~8% increasing at dried season. Also, the period of drought season was significantly extended for almost 2 moths and the frequencies of heavy rainfall amount rapidly increase in Kao-ping watershed located at the southern Taiwan.

Site characterization

Kao-ping watershed has total area of 3257km2. Of which more than 80% is classified as slope land. These areas are humid and tropical with annual precipitation ranges from 1980 to 4350mm. The extreme temperature range fluctuated from 10oC to 34 oC which is characterized as a tropical region. Approximately 70% of the annual precipitation falls in the months June to August. This watershed is located within the western foothills geologic province of Neocene elastic sediments. The predominant underlying rock is Nan-Hwa & Yu-ching formations composed of siltstone, mudstone, shale and part of organic limestone reefs in a monotonous alternating sequence. Soils in the studied area lie in the transition zone of Entisols and Inceptisols. The soils in these areas are weakly developed and usually silt clay loam or clayey loam in texture. Entisols and Inceptisols are locally common due to the steep slope and surface erosion within the watershed.

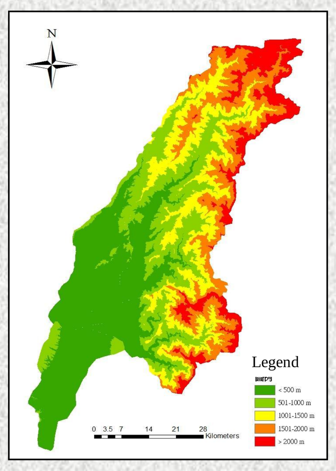

Fig. 1 The DEM of Kaoping watershed

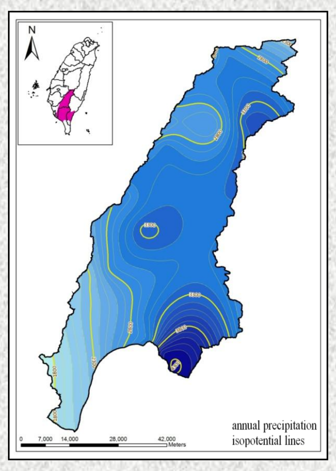

Fig. 2 The monthly rainfall distribution in Kaoping watershed

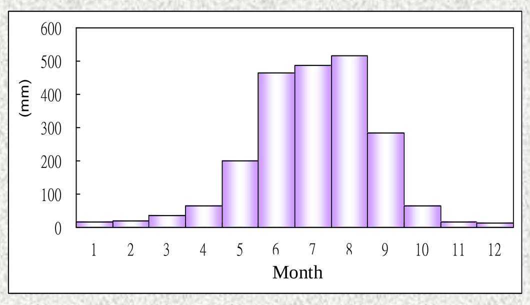

Fig. 3 The contour map of annual precipitation in Kaoping watershed

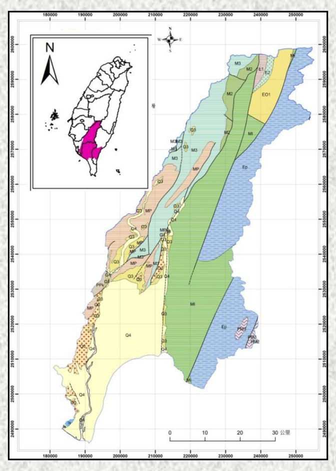

Fig. 4 The geological map of Kaoping watershed

Table 1 The elevation distribution of Kaoping watershed

Elevation(m)	Area(ha)	(%)
<100	71,229	21.87
100~500	50,189	15.41
500~1000	51,679	15.87
1000~2000	96,899	29.78
>2000	55,704	17.10
Total	325,700	100.00

IHA analysis

Fig. 9 through 11 and Table 2 illustrate the typical results of this research. These accompanying tables and figures show how various environmental parameters affect the results. Table 2 shows the variation of IHA are strong developed related from the hydrologic environment of Kaoping River. Much more important is the influence of high discharge and frequency of high/low flow conditions content. This caused a further decrease and increase of hydrologic environmental impact effect.

Table 2 The output data calculated by using IHA Analysis

IHA Classification		Degree of hydrologic alteration (D:%)	
		Ai-Liao River Sandimen Township	Qishan River Shanlin Main Bridge
1st Group	The average of annual discharge	1month:29.4 7 month:5.9 2 month:17.6 8 month:29.4 3 month:5.9 9 month:5.9 4 month:17.6 10 month:41.2 5 month:17.6 11 month:5.9 6 month:5.9 12 month:17.6	1 month:50 7 month:25 2 month:50 8 month:0 3 month:50 9 month:0 4 month:25 10 month:50 5 month:25 11 month:50 6 month:0 12 month:100
2nd Group	Extreme value of annual discharge	5.9 (min 1dy) 52.9(max 1dy) 5.9 (min 3dy) 52.9 (max 3dy) 5.9 (min 7dy) 5.9 (max 7dy) 17.6 (min 30dy) 5.9 (max 30dy) 17.6 (min 90dy) 5.9 (max 90dy) Q(min 7dy) / Q(yr)：17.6	25 (min 1dy) 0(max 1dy) 25(min 3dy) 25 (max 3dy) 25 (min 7dy) 0 (max 7dy) 50 (min 30dy) 0 (max 30dy) 0 (min 90dy) 25 (max 90dy) Q(min 7dy) / Q(yr)：75
3rd Group	Time of extreme discharge	Min:52.9 Max:29.4	Min:75 Max:50
4th Group	Duration and frequency of max & min discharge	Frequency of low discharge:64.7 Frequency of high discharge:5.9 Duration of low:41.2 Duration of high:64.7	Frequency of low discharge:100 Frequency of high discharge:25 Duration of low:75 Duration of high:25
5th Group		Decrease ratio of discharge:5.9 Increase ratio of discharge:17.6 The reverse frequency variation between high & low discharge:29.4	Decrease ratio of discharge:75 Increase ratio of discharge:75 The reverse frequency variation between high & low discharge:75

Acknowledgements

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Introduction

The problem of sediment related disasters occurred at the southwestern Taiwan is strong related to both heavy rainfall and human activities such as deforestations, land use development and roads construction. The Kao-ping watershed is one of the major water resources regions for the Kaohsiung city development in southern Taiwan. The negative effect of these disasters on the growth of city is significant to the development of Kaohsiung metropolitan. Various studies have shown that all disasters occurred at these regions are related to heavy rainfall amount. Therefore, the possible approach used to prevent these regions from those disasters attack was to intensively perform the field investigations by using GPS/GIS/RS. As a result, indispensable hydrological analysis, soil characteristics investigation, geomorphologic comparison, statistic inference and Indicator of hydrologic alteration (IHA) study should meet propose of this research. (Richter, 1996) Also, the critical heavy rainfall events, including typhoon & thunderstorm, during the past 10 years became an important issue which should be collected and analyzed by using HEC-RAC model development from American Army Corps Engineering, USA.

Variation analysis of hydrologic environment

The variation analysis of hydrologic for the Kaoping watershed was investigated by using both aerial-photo interpretation and HEC-RAS Models developed from American Army Corps Engineering. The purpose of hydrologic environment analysis is to determine the nature's causes, variation and diversities of each flow section of river systems that may have a detrimental effect on the stabilization and equilibrium of environmental and ecological situation to downstream. Detail analysis of hydrology by using HEC-RAS and Log-Pearson/Pearson type III method is necessary. Equation 1~4 & Fig. 5~8 can be used to demonstrated the actual simulations and calculation of each flow profiles based on the discharge and sedimentation data collected from different river stations set up by Water Resource Agency for almost 30 years. All results got from both HEC-RAS and frequency analysis of hydrology can be displayed as Fig. 5~9:

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \quad (1)$$

$$h_e = L\bar{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \quad (2)$$

$$L = \frac{L_{lob}\bar{Q}_{lob} + L_{ch}\bar{Q}_{ch} + L_{rob}\bar{Q}_{rob}}{\bar{Q}_{lob} + \bar{Q}_{ch} + \bar{Q}_{rob}} \quad (3)$$

$$S_f = \left(\frac{Q}{k}\right)^2 \quad (4)$$

$$D = \left|\frac{No - Ne}{Ne}\right| \times 100\% \quad (5)$$

where
Y : Depth of flow
Z : Elevation of river bed
g : Acceleration
V : Average velocity of flow
α : Coefficient of energy
h_e : Hydraulic head losses
L : The length of channel
$\bar{S}_f$: Slope gradient between two flow section
C : Coefficient of Head losses
Llob，Lch，Lrob : Length of each river cross-section
Qlob，Qch，Qrob : Average discharge of each river cross-section
D: Degree of hydrologic alteration
No : Number of observation (year)
Ne: Number of predication (year)

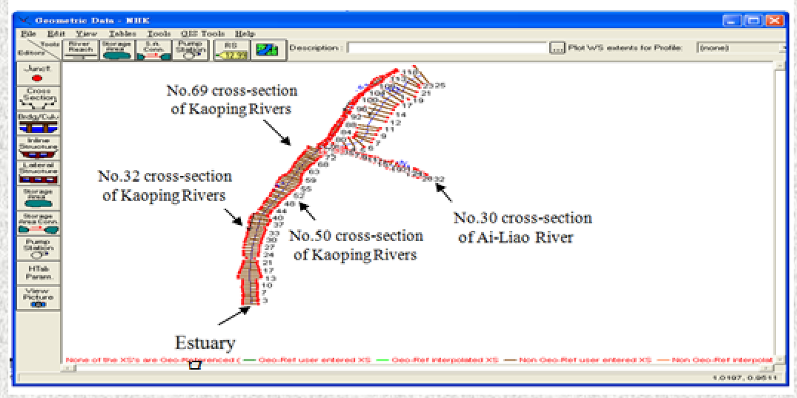


Fig. 5 Each river cross-section of Kaoping Rivers

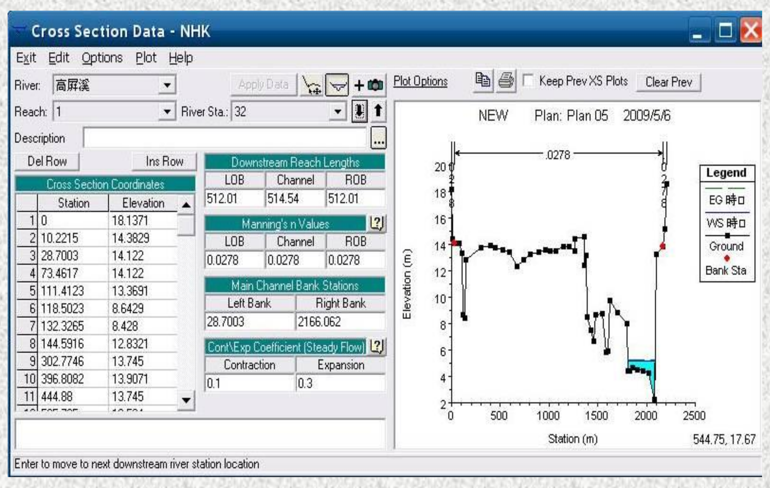


Fig. 6 The input data interface of each flow channel section

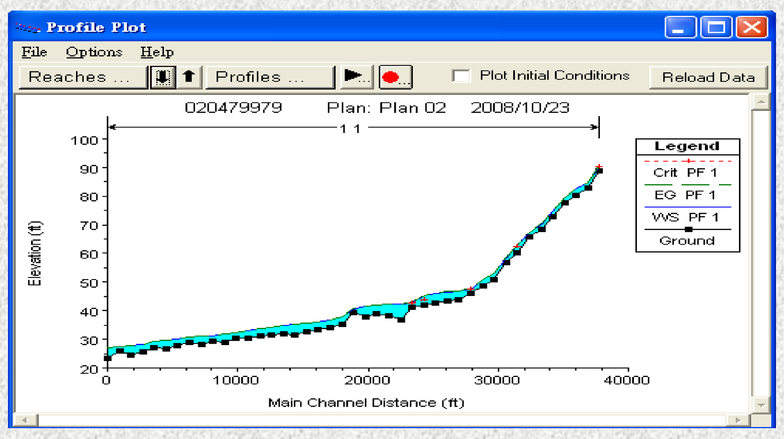


Fig. 7 Flow profiles routing and calculation

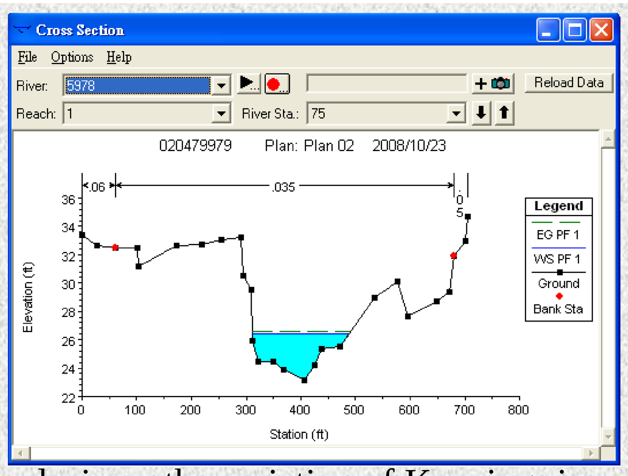
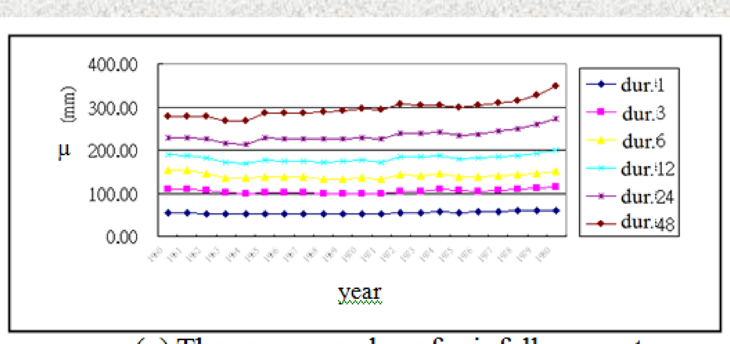
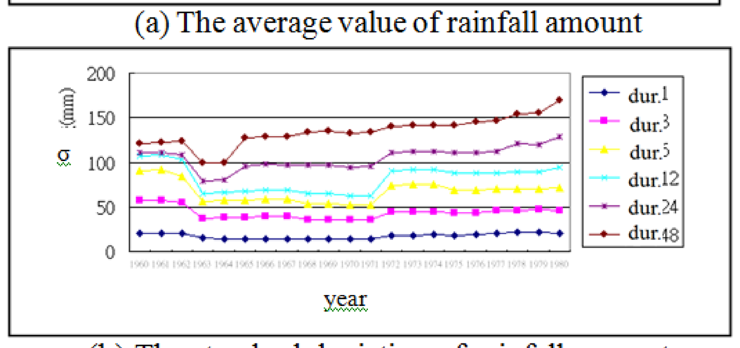


Fig. 8 Analysis on the variation of Kaoping river profiles



(a) The average value of rainfall amount



(b) The standard deviation of rainfall amount

Fig. 9 The trend analysis of heavy rainfall event based on different rainfall duration (a & b)

Conclusions

1. Major factors associated with hydrologic environment of Kaoping watershed are predominated by weakly geological structure of mudstones, extremely rainfall intensity poorly developed soil formation and intensive human activities within the watershed.
2. GPS/GIS/RS technology integrated with IHA analysis & HEC-RAS model can be successfully used to identify the high potential impact risk or probability of hydrologic environment variation.
3. The degree of variation (D-value) have 7 hydrologic parameters can be classified as medium impact on the environment variation. However, 8 parameters are grouped into high degree of impact variation, especially increasing the duration and frequency of rainfall, discharge and concentration of suspension loads were rising up 25~33% more than before and almost 60-day extension of dried season in Kaoping watershed.