Journal of Hydrology 410 (2011) 226–238

Contents lists available at SciVerse ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Effects of land cover on runoff coefficient

Nutchanart Sriwongsitanon *, Wisuwat Taesombat

Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand

ARTICLE INFO

Article history:
Received 4 June 2010
Received in revised form 18 May 2011
Accepted 18 September 2011
Available online 29 September 2011
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief, with the assistance of V. Lakshmi, Associate Editor

Keywords:
Landsat 5 TM
Land cover
Flood hydrology
Runoff coefficient
Peak flood events
Upper Ping River Basin

SUMMARY

Land cover is considered to have significant influence on the hydrologic response of a river basin. In this study, we assessed how changes in land cover over time affected flood behaviour from 1988 to 2005, in the Upper Ping River Basin, northern Thailand. We correlated the types of land cover with rainfall–runoff behaviour for smaller and larger flood events taking place during this period. To quantify land cover, nine Landsat 5 TM images taken during the dry season (January or February) were obtained and processed to examine inter-annual land cover changes. From the networks of daily read rainfall data and stream gaugings available across the basin, 68 rainfall and 11 runoff stations were selected to evaluate peak flow rate and runoff coefficient for flood events. For individual sub-catchments, strong non-linear correlations were found between the overall runoff coefficient and peak flow rates for flood events. These runoff coefficients to peak flow relationships varied from year to year with different land cover for each sub-catchment. From these relationships within a particular sub-catchment, we determined relationships between different types of land cover and runoff coefficient for the 2, 5, 10 and 15 year Annual Recurrence Interval (ARI) peak flood events. We found that runoff coefficient increased with increasing forest proportion for these specified peak flood conditions, on nine out of eleven sub-catchments. On the other hand, the runoff coefficient associated with these peak flood events decreased as agricultural and disturbed forest areas increased. The influence of land cover on runoff coefficient was, however, found to be very different between smaller (lower than ~2 year ARI) and larger flood events (larger than ~2 year ARI). Runoff coefficient is higher for high forest cover during larger flood events; but for smaller flood events, runoff coefficient is lower when forest cover is high. This is due to the fact that for smaller flood events, rainfall loss rate for the forest area is normally higher than that of the non-forest area according to higher evapotranspiration and soil moisture capacity. Forests have proved to potentially offer flood mitigation benefits for smaller flood events. However, for larger flood events the situation of the basin can be different, especially on a basin with higher antecedent soil moisture or even under saturation stage. Antecedent soil moisture from the previous storms could be better retained within the forest area than the non-forest area due to deeper rote zone and higher soil moisture holding capacity of the forest area compared to non-forest area. For the larger flood events, forest area tends to produce more runoff than non-forest area as found in this study. These findings gave us a more thorough understanding of the effect of land cover types on flood behaviour at different stages of soil moisture conditions, and the severity of storm events. It can be useful for land use and flood management of the river basin.

1. Introduction

Internationally, there has been much concern for quite some time that deforestation of upland catchments may alter downstream flood hydrology. This concern has been fostered by the strong evidence that deforestation leads to increased flooding on scales smaller than 2 km^2 (Bosch and Hewlett, 1982). However, for larger catchments the situation is more complex. The limited numbers of studies that have quantified effects of land cover changes on flood behaviour report a diversity of results. Some studies reported that deforestation is linked with an increase in flood peaks and flood volumes (Bates and Henry, 1928; Fritsch, 1990; Lavabre et al., 1993), a number of other studies finding no definite change in flood behaviour (Hibbert, 1967; McGuinness and Harrold, 1971; Hewlett, 1982; Robinson et al., 1991; Beschta et al., 2000; Andréassian, 2004), and some studies even showing evidence that flooding reduces as deforestation occurs (Troendle and King, 1985; Hornbeck et al., 1997; Austin, 1999).

Lin and Wei (2008) provide a good example of a large scale study showing a trend of increased flooding with decreasing forest cover.

* Corresponding author. Address: Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, 50 Paholyothin Rd., Ladyao, Jatujak, Bangkok 10900, Thailand. Tel./fax: +66 2 5791567.

E-mail addresses: fengnns@ku.ac.th (N. Sriwongsitanon), fengwwt@ku.ac.th (W. Taesombat).

0022-1694/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhydrol.2011.09.021

Their study was conducted in the Willow catchment (2860 km^2) in Canada. The majority of the catchment consists of a long, broad valley at low to medium elevations and gentle to moderate slopes. They showed evidence that deforestation in the catchment significantly increased mean and peak flows between 1957 and 2005 during spring periods; however, the mean and peak flows in summer and winter were not significantly affected. Legesse et al. (2003) also concluded – in their study on hydrological response of a catchment to climate and land use changes in south-central Ethiopia – that changing a catchment which is dominantly covered by cultivated/grazing land to woodland, would increase the evaporation loss and decrease mean annual discharge. More broadly, in a study based on a dataset of national statistics of land cover change and flood characteristics, Bradshaw et al. (2007) concluded that deforestation is strongly correlated with flood occurrence and severity. However, Van Dijk et al. (2009) re-examined this data set and concluded that the understanding of how deforestation impacts on hydrology for large scale catchments is far from complete. They went on to cite many recent studies on large-scale catchments that found no significant changes in hydrology even after deforestation of up to 50% of the catchment. Furthermore, they found that where changes did occur, these were not directly attributable to deforestation. Van Dijk et al. (2009) concluded that until now, there has not been convincing empirical evidence or theoretical argument that removal of trees is likely to increase severe flooding.

Case studies that showed flood flows on large-scale catchments were not significantly affected by land cover change include Buttle and Metcalfe (2000) who found only limited flow responses to land cover changes of 5–25%, for catchments in Northeastern Ontario, Canada, with no definitive changes in annual flood peak. Dyhr-Nielsen (1986) also concluded that there were no significant trends in streamflow in the Pasak River Basin in Central Thailand, where changes in forest cover of up to 50% were observed. Wilk et al. (2001) did not find any significant change in hydrological behaviour after deforestation in the Nam Pong River Basin in northeastern Thailand when forest cover declined from 80% in 1957 to 27% in 1995. Adamson (2005) also reported that there were no definitive changes in the observed river hydrology of the Mekong River Basin over the last 90 years, despite the significant land cover changes in the basin during that period.

Few studies have shown deforestation to be linked to a decrease in peak flows (Wei et al., 2008). A particularly significant study reported this trend was conducted on the Upper Penticton experimental basin in British Columbia, Canada (Austin, 1999).

After Andréassian (2004) carried out a thorough review on the paired-watershed experiments conducted throughout 20th century, he concluded that deforestation could definitely increase both flood volumes and flood peaks. However, this effect is much more variable than the effect on total flow and may even be inverted in some years or in some seasons. In some studies on reforestation, they show a very limited effect on floods in general, and no effect at all on the large ones. This corresponds to the conclusion made by Cosandey et al. (2005), who noted that the forest has a limited impact in the case of very heavy floods, whereas its effect has been confirmed when flood flows are lower. This is associated with the scientific perception which appreciates that forests generally evaporate more water than other land uses which tends to lead to a general reduction in catchment flows (Calder and Aylward, 2006). From theoretical considerations, it would be expected that interception of rainfall by forests reduces floods by removing a proportion of the storm rainfall, and by allowing the build up of soil moisture deficits, rather than leaving it to soak into the rivers and streams until the soil becomes saturated. After that, the water stops infiltrating into the soil and all of it flows into the waterways. When we have major floods, the soils become saturated early on; and once they are saturated it does not matter whether or not there is forest or any other types of land cover (Lull and Reinhart, 1972).

Until 30 years ago, the heterogeneous nature of land cover changes across large catchments made their accurate assessment difficult. However, remote sensing now provides an invaluable tool for accurately detecting land cover change.

Through this paper we seek to improve the understanding of land cover impacts on flood behaviour by analyzing data available for the Upper Ping River Basin (UPRB) by: (1) determining the land cover changes from 1988 to 2005 using the Landsat 5 TM satellite images, (2) calculating the runoff coefficient for runoff stations for monsoonal flood events within the same period, and (3) determining correlative relationships between different types of land cover and runoff coefficients for those flood events.

2. The study area

The Ping River is one of the main tributaries of the largest river basin within Thailand, the Chao Phraya, which drains more than one-third of the country's land area, making it Thailand's largest river basin. The Ping originates in the far north of Thailand in Chiang Dao District. From there it flows south through Chiang Mai City into the Bhumibol Reservoir, which has an active storage capacity of 9.7×10^9 m^3, as shown in Fig. 1. It is this portion above the Bhumibol Reservoir that is referred to as the UPRB.

With Thailand's economic development, there is increasing concern about land cover changes and flooding in the Chao Praya Basin. For example, between 25 and 30 September 2005, Typhoon Damrey devastated the UPRB, displacing 24395 people and causing around 100 million baht (3 million US dollars) of widespread economic damage across Chiang Mai Province (Department of Disaster Prevention and Mitigation, 2005).

The UPRB has an area of approximately 25370 km^2 and is located between 16°54′ and 19°51′N latitude, 97°48′ and 99°36′E longitude. The basin is dominated by well-forested, steep mountains in a generally north–south alignment. The average annual rainfall and runoff of the basin between 1988 and 2005 were 1174 mm and 268 mm, respectively (Taesombat and Sriwongsitanon, 2010). Eleven sub-catchments with the areas ranging between 240 and 3858 km^2 were used in the study and their average catchment area is around 1667 km^2.

Flooding is an issue of critical concern for water resources management in the UPRB. Floods on the UPRB occur annually due to heavy seasonal rains from both the south-west monsoon and tropical storms related to typhoon events in the South China Sea.

Historically, the UPRB was a heavily forested landscape, but by 2006 forest cover had declined to 72% (Royal Forest Department, 2006). Over the last 30–40 years, this deforestation on the UPRB has occurred due to agriculture and the expansion of urban communities. Much of this deforestation has been driven by economic development in and around Chiang Mai, a city of around 2 million people and northern Thailand's most important economic urban centre, which is located in the north-central area of the UPRB. There has been much speculation that deforestation has increased the risk of flooding on the Upper Ping and its tributaries; however, to date, few studies have directly addressed the links between changing land cover and flooding in the UPRB, in a rigorous manner.

3. Data collection and catchment characterizations

Relationships between different types of land cover and runoff coefficients for the UPRB were investigated in this study using TM satellite images, as well as rainfall and runoff data, during the same period. Details of data used are described below.