Second International Conference on Science, Engineering & Environment, Osaka City, Japan, Nov.21-23, 2016, ISBN: 978-4-9905958-7-6 C3051

EFFECT OF SLOPE ADJUSTMENT ON CURVE NUMBER USING GLOBAL DIGITAL ELEVATION DATA: NEW LOOK INTO SHARPLY-WILLIAMS AND HUANG METHODS

Abolghasem Akbari[1], Azizan Abu Samah[2] and Su Kong Ngien[1]
[1]Faculty of Civil Engineering & Earth Resources, University Malaysia Pahang (UMP), Malaysia
[2]The Institute of Ocean and Earth Sciences (IOES), University of Malaya, Malaysia

ABSTRACT

The Natural Resources Conservation Service Curve Number (NRCS-CN) method is highly recommended for runoff prediction in many climate conditions. The key parameters to obtain CN values are hydrologic soil groups and land use information with respect to soil moisture conditions. This method has been well documented and available in many popular rainfall-runoff models such as HEC-HMS, Mike, SWAT and many more. It is also easy to implement due to availability of required data in many countries. However, it is criticized in a way that NRCS-CN do not take into account the effect of terrain slope and drainage area. This study aimed to investigate the effect of slope on CN and the way that slope could change the domain of CN values in Kuantan River Basin (KRB), Malaysia. The Huang and Sharply-Williams methods were used to investigate the changes on CN values provided in National Handbook of Engineering. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) version 2 was used to derive slope map with spatial resolution of 30 m for the study area. The study significantly enhanced the application of GIS tools and recent advances in earth observation technology in order to analyze hydrological process with respect to spatial dimension.

Keywords: ASTER-GDEM, GIS, Kuantan, NRCS-CN

INTRODUCTION

The Soil Conservation Service Curve Number (SCS-CN) methods is empirical equation which have been widely used in different studies. CN is an empirical parameter which is used for estimation of initial abstraction or infiltration from rainfall excess [1]-[3]. Regardless of some weaknesses, the CN approach provide some advantages such as ease of use and availability of data in many places. As result, the NRCS-CN method which originally intended for the study of agricultural land, became a fundamental part of hydrological practice and was adopted for application in different climate and conditions [1]. Moreover the CN method has been integrated into different hydrological models, including CREAMS [2], FEST [3, 4], EPIC [3], AGNPS [4], HEC-HMS [5] and SWAT [6]. There are many research articles and classical books in supporting and criticizing the CN method. Among them the works of Hawkins [7], [8], Hawkins et al. [7], Huang et al. [8, 9], Garen and Moore [8], Mishra et al. [9, 10] and Michel et al. [9] are notable. Review of literature shows that considerable attempted has been made for adjustment and adaptation of CN method for unaccented factors including drainage area [10], [11], soil moisture proxies [8, 10, 11, 32], slope [3, 10] and more recently Kakuturu et al. [10] investigated the effect of slope on estimation of CN values. The CN value have been adjusted for slope in Kuantan KRB [11] using Huang and Sharply-Williams. However, the effect of slope adjustment for CN did not investigated in respect to the spatial domain using available methods. The main objective of this research is to take another look into the effect of slope adjustment of CN with respect to the spatial variation of the terrain slope in KRB.

NRCS-CN approach

The traditional form of NRCS-CN equation is given by Eq. (1):

$$q = \begin{cases} 0 & \text{for } P \le I_a \\ \frac{(P-I_a)^2}{P-I_a+S} & \text{for } P > I_a \end{cases} \quad (1)$$

Where; q is direct runoff (mm), P is rainfall (mm), S is the potential maximum soil moisture retention after runoff begins (mm), I_a is the initial loss (mm), or the amount of water before runoff, such I_a as infiltration, or rainfall interception by vegetation originally, it has been assumed that $\frac{I_a}{S} = \lambda = 0.20$ [12], but more recent research [13] has shown that taking $\lambda = 0.05$ provide more accurate estimation for runoff. The potential maximum storage is obtained through the Eq. (2):

$$S = \frac{25400}{CN} - 254$$

Or

$$\mathrm{CN} = \frac{25400}{254+S} \quad (2)$$

As the S range from zero to infinity, the CN can take value from 0 to 100 which is obtained from the NRCS standard tables. The larger value represent higher runoff potential and the lower value indicate low runoff potential.

Revised NRCS-CN method

Recent studies have shown $\lambda = 0.05$ provide a better prediction for runoff estimation. Details about the applied methodology and result from the work done by Woodward et al is referred to the reference [13].

RESEARCH MATERIALS

Location

The KRB located on East Coast of peninsular Malaysia was selected as case study (see Fig. 1).

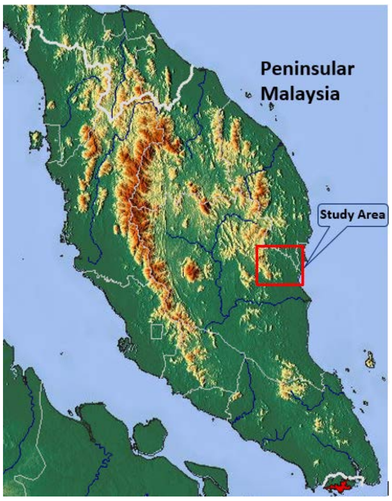

Fig. 1 Layout of the study area.

Data

Spatial data for this research including Hydrologic Soil Group (HSG) and Land Use (LU) maps were obtained from National Hydraulic Research Institute of Malaysia (NAHRIM) in vector format (ESRI shape file) projected in Kertau-RSO-Malaysia metric coordinate system. This dataset have been originally produced by Department of Agriculture (DOA) in Malaysia. According to DOA, the LU is representing the condition for 2013 and HSG have been generated in 2010. Main LU classes are forest (49%) and Palm (27%). The HSG map contains five HSG class including A&C, A&D, C&B, B and C. Predominate HSG in the study area are B, A&C, C&B with 56%, 15% and 15% respectively. The slope map was derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2). It is freely available for download from NASA Re verb, LP DAAC Global Data Explorer, and J-space-systems ASTER-GDEM Page. The cell size of elevation data is 28×28 meter.

Software

The Integrated Land and Water Information System ILWIS 3.8 which is public domain raster-based GIS software was used for spatial data development and spatial analysis. ILWIS have high performance in geospatial analysis and image processing with friendly graphical user interface.

RESULT AND DISCUSSION

A two-dimensional table was created to combine and reclassify two raster maps including LU and HSG with class domain. Two-dimensional defines a value for each possible combination of input classes [14]. This automated processor used to generate CN map for the study area. Terrain slope of the study area was derived from ASTER-GDEM (See Fig. 2b).

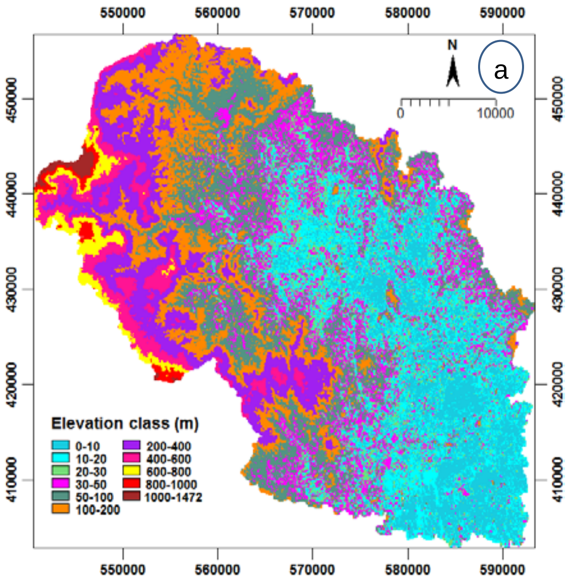

Fig. 2a Classified ASTER-GDEM of study area.

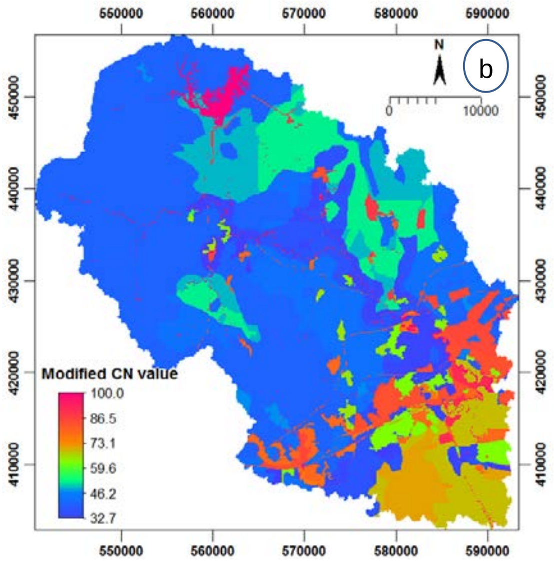

Fig. 2b Modified CN map of study area.

To obtain the modified CN map, transfer equation introduced by Woodward et al. [13] was employed. As it evident in Fig. 2.b, the CN values rage from 32.7 to 100 and predominate value change from 55 to 40 (39% area).

Slope adjustment of CN

It is recommended to adjust CN for slope because terrain slope can effect on runoff prediction by reduction in I_a [15], infiltration [16] and recession time of overland flow [17]. To perform this step, CN map was adjusted for slope using Sharply-Williams and Huang methods.

Sharply-Williams method

Slope adjustment was made based on the Sharply-Williams and Huang methods presented in Eq. (3) and Eq. (4). ILWIS GIS software was used for geospatial analysis and mapping.

$$CN_{SW} = \frac{1}{3}(CN_w - CN_m)(1 - 2e^{-13.86\alpha}) + CN_m \quad (3)$$

Where, CN_{SW} is the slope adjusted CN by Sharply-Williams method, CN_w is CN for wet soil moisture condition. The CN_m represent CN for moderate soil moisture condition, α is terrain slope m/m.

$$CN_w = \frac{100 * CN_m}{43 + 0.57CN_m} \quad (4)$$

It is noted that the CN values provided in TR55 represent the moderate soil moisture condition. Equation 4 is used to transfer CN_m into CN_w as it required by Sharply-Williams method. Slope-adjusted CN by Sharply-Williams is shown in Fig. 3a. The CN domain values have the range from 11.8 to 102.8.

Huang method

Huang [18] has introduced adjustment Eq. (5) for slope as shown in below:

$$CN_H = CN_m * \frac{322.79 + 15.63\alpha}{\alpha + 323.52} \quad (5)$$

Where; α is terrain slope m/m with respect to limited domain of 14-140%. It is believed that the Huang et al. method provide more reasonable adjustment for slope and therefore runoff prediction in the steep watersheds [18]. Slope-adjusted CN by Huang is shown in Fig. 3b. The CN domain values have the range from 17 to 104.6. To investigate the quantity of change on CN as result of slope adjustment in spatial domain, the difference between the adjusted and non-adjusted CN were calculated for both method using map calculation tools of ILWIS (See Fig. 4). The histogram generated from the two calculated maps shows the spatial distribution and relationship between the magnitude of changes in CN and number of pixels (See Fig. 5).

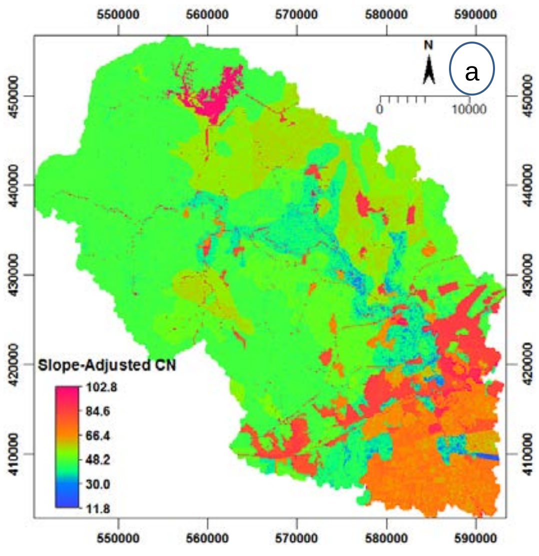

Fig. 3a Slope-adjusted CN by Sharply-Williams method.

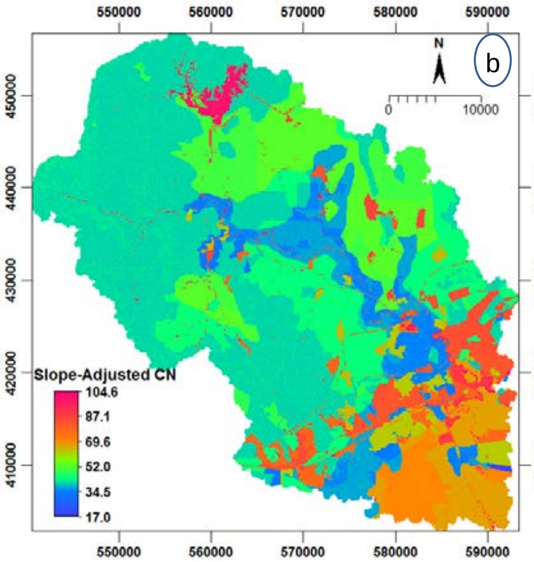

Fig. 3b Slope-adjusted CN by Huang method.

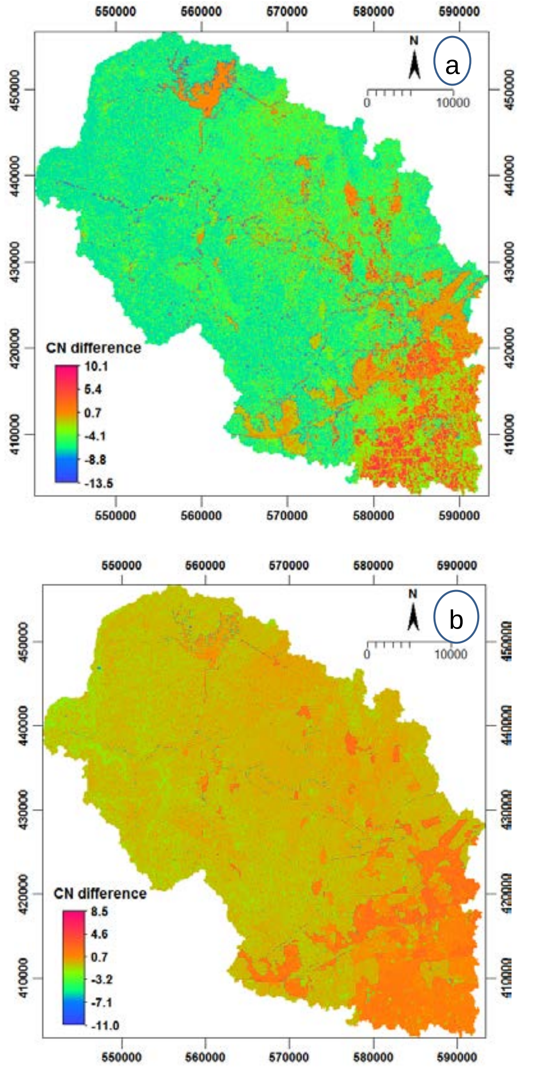

Fig. 4 Illustration of difference in slope-adjusted CN using a) Sharply-Williams and b) Huang, compare to none slope-adjusted CN

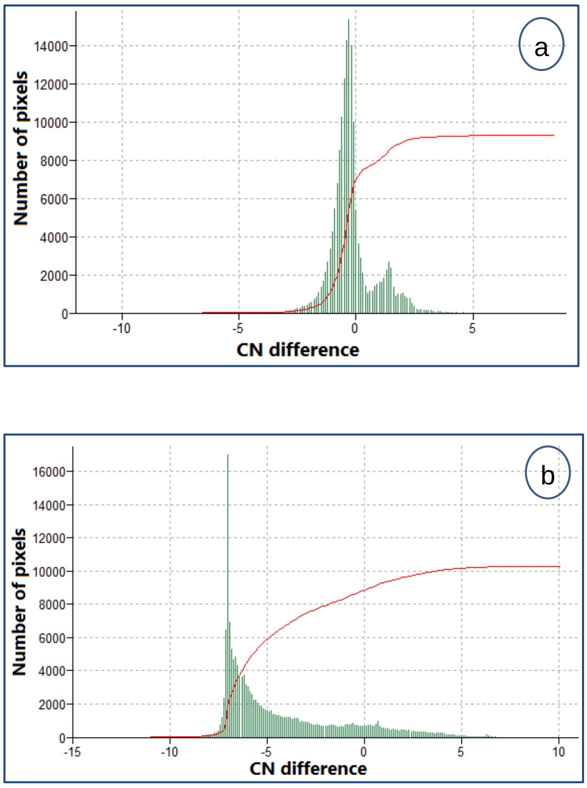

Fig. 5 Illustration of difference between the slope adjusted and non-adjusted CN for slope using a) Sharply-Williams and b) Huang method.

CONCLUSION

This study demonstrate the practical use of GIS tool in spatial analysis for hydrological process. It is evident from the result of this study that both method expanding the domain of CN to the lower and upper limits. It is also observed that both method have error in calculation of slope-adjusted CN at the upper domain as 102.8 and 104.5 are obtained from Sharply-Williams and Huang method respectively. It means stretching effect in both method do not limit with the maximum possible value for CN which is 100. In addition, the difference between the unjustified CN with slope-adjusted CNs, shows that both method tend to decrease the CN values (negative values) in the areas with the mild and flat slope while CN values are increased (positive values) in relatively high and steep areas. However, as illustrated in Fig. 6, in the same area Huang method significantly tend to increase the CN values in more number pixels compare to Sharply-Williams. This study can be further develop by performing in different river basins with more variety of terrain slope method.

ACKNOWLEDGMENT

The authors acknowledge the University Malaysia Pahang and the Institute of Ocean and Earth Sciences, University Malaya for supporting this research through the grant numbers RD150127 and IOES-2014B.

REFERENCES

[1] USDA, Urban Hydrology for Small Watersheds. United States Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division: Washington DC, USA, 1986, pp. 164.

[2] Mahdavi, M., Applied Hydrology, vol.2, Tehran university, 2005.

[3] Alizadeh, A., Principles of applied hydrology, Astane Ghods: Mashhad, Iran. 2006 pp. 350.

[4] Miliani, F., G. Ravazzani, and M. Mancini, Adaptation of Precipitation Index for the Estimation of Antecedent Moisture Condition in Large Mountainous Basins. Journal of Hydrologic Engineering, Vol. 16(3), 2010, pp. 218-227.

[5] Knisel, W.G., CREAMS: A field-scale model for chemicals, runoff and erosion from agricultural management systems. USDA Conservation Research Report, 1980.

[6] Montaldo, N., G. Ravazzani, and M. Mancini, On the prediction of the Toce alpine basin floods with distributed hydrologic models. Hydrological processes, Vol.21 (5), 2007, pp. 608-621.

[7] Rabuffetti, D., et al., Verification of operational Quantitative Discharge Forecast (QDF) for a regional warning system–the AMPHORE case studies in the upper Po River. Natural Hazards and Earth System Science, Vol.8 (1), 2008, pp. 161-173.

[8] Sharpley, A.N. and J.R. Williams, EPIC-erosion/productivity impact calculator: 1. Model documentation. Technical Bulletin-United States Department of Agriculture, 1990 (1768 Pt 1).

[9] Young, R.A., et al., AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. Journal of soil and water conservation, Vol.44 (2), 1989, pp.168-173.

[10] Feldman, A., Hydrologic Modeling System (HEC-HMS): Technical Reference Manual., U.S. Army Corps of Engineers: Washington DC, 2000, pp. 158.

[11] Neitsch, S., et al., Soil and water assessment tool theoretical documentation. Texas, USA, 2005.

[12] Hawkins, R.H., Runoff curve numbers with varying site moisture. Journal of the Irrigation and Drainage Division, Vol.104 (4): p. 389-398.

[13] Hawkins, R.H., Asymptotic determination of runoff curve numbers from data. Journal of Irrigation and Drainage Engineering, 1993. Vol.119 (2), 1978, pp. 334-345.

[14] Hawkins, R.H., et al., Curve Number Hydrology: State of the Practice, ed. R.H. Hawkins., Virginia, USA: American Society of Civil Engineers. 2009, pp.116.

[15] Huang, M., et al., A modification to the Soil Conservation Service curve number method for steep slopes in the Loess Plateau of China. Hydrological processes, Vol.20 (3), 2006, pp.579-589.

[16] Huang, M., et al., Use of soil moisture data and curve number method for estimating runoff in the Loess Plateau of China. Hydrological processes, Vol.21 (11), 2007, pp.1471-1481.

[17] Garen, D.C. and D.S. Moore, CURVE NUMBER HYDROLOGY IN WATER QUALITY MODELING: USES, ABUSES, AND FUTURE DIRECTIONS1. JAWRA Journal of the American Water Resources Association, Vol.41 (2), 2005, pp.377-388.

[18] Mishra, S., et al., A modified SCS-CN method: characterization and testing. Water Resources Management, Vol.17 (1), 2003, pp.37-68.

[19] Mishra, S., et al., SCS-CN-based modeling of sediment yield. Journal of Hydrology, Vol.324 (1), 2006, pp. 301-322.

[20] Michel, C., V. Andréassian, and C. Perrin, Soil Conservation Service Curve Number method: How to mend a wrong soil moisture accounting procedure? Water Resources Research, Vol.41 (2), 2005, pp.45-66.

[21] Simanton, J. and N. Sutter, Procedures for identifying parameters affecting storm runoff volumes in a semiarid environment. USDA, ARS. ARS-W, 1973. 1.

[22] Simanton, J., et al., Runoff curve number variation with drainage area, Walnut Gulch, Arizona. Transactions of the ASAE, Vol.39 (4), 1996, pp.1391-1394.

[23] Ponce, V.M. and R.H. Hawkins, Runoff curve number: Has it reached maturity? Journal of hydrologic engineering, Vol.1 (1), 1996, pp.11-19.

[24] Beck, H.E., et al., Improving curve number based storm runoff estimates using soil moisture proxies. Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of, Vol.2 (4), 2009, pp. 250-259.

[25] Kakuturu, S.P., et al., Runoff Curve Numbers for Simulated Highway Slopes under Different Slope, Soil-Turf, and Rainfall Conditions. Journal of Hydrologic Engineering, Vol.18 (3), 2013, pp. 299-306.