Image Recognition Applied to the Zhuoshui River Basin Runoff Variations

Chia-Cheng Yeh (1)(2), Yang-Lang Chang (2), Jin-Cheng Fu (1), Chun-Mao Huang (1)

[1] National Science and Technology Center for Disaster Reduction, 9F., No.200, Sec. 3, Beisin Rd., Xindian District, New Taipei City 23143, Taiwan, R.O.C.
[2] National Taipei University of Technology, 1, Sec. 3, Zhongxiao E. Rd., Taipei 10608, Taiwan, R.O.C
Email: andrew@ncdr.nat.gov.tw; ylchang@mail.ntut.edu.tw;
jcfu@ncdr.nat.gov.tw; cmh@ncdr.nat.gov.tw

KEY WORDS: Zhuoshui River Basin, land use change, surface runoff, Low Impact Development

ABSTRACT: The scope of the study covers the Zhuoshui River Basin. Firstly, the multi-time-sequence satellite images of ground features were classified by object-oriented classification, with spectral characteristics as classification indicators. The classification results went through land use change analysis, and then the hydrological model was used to simulate land use change and changes in runoff. In the study, hot spot analysis was used to select the catchment area with high concentration of artificial structures in the Zhuoshui River Basin as the research object of catchment scales. Under the catchment scale, the data of the Current Land Use survey was used along with that of urban/non-urban land use plans so as to compare land use changes before and after such development plans, and changes in runoff was obtained through the simulation model. In addition, the Storm Water Management Model (SWMM) was used to simulate runoff variation in the metropolitan scale so as to understand the impact of land use change on the metropolitan area, after which Low Impact Development was introduced according to the impact levels. The results of the study show that the runoff in the Zhushan Urban Planning Area can improve after the development of land use plan is complete. Therefore, the runoff tend to improve under the 5-year recurrent interval if the Low Impact Development is introduced in time.

1. Introduction

As a result of economic progress, population and industrial density continues to increase. Under intensive land development, people's demand for life safety and quality of living also grows stronger year after year. Nonetheless, increasing impervious surfaces in river basins caused by high-level land development reduces the permeability and water retention rate of land. When typhoons and torrential rains come, the probability of flooding becomes relatively higher and serious losses of lives and property happen. Therefore, analysis of land use changes around catchment areas in various river basins to know the increase and decrease of surface runoff after land development in order to work out and implement different flood-reducing measures and introduce the concept of low-impact development to make adjustments, reduce disasters, enhance the resilience of land in river basins, improve the residential safety of people and cut down property damage has become an important issue.

As pointed out in related literature from in and outside the country, changes of patterns of land use have significant influence on runoff. The increase of impervious surfaces has made infiltration impossible for existing water bodies and the water turns into surface runoff directly. For this reason, it is necessary to apply appropriate hydrologic models to simulate the volumes of runoff changes in different periods to clarify the relationship between land use changes and runoff. The Hydrologic Modeling System (HMS) is a new consolidated window-type rainfall-runoff module developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers (USACE) by adopting the flood forecasting model HEC-1 as the foundation and combining it with a geographic information system and a graphical user interface, as well as incorporating object-oriented concepts. In Taiwan and other countries, satellite image processing techniques and geographic information systems have also been used to conduct physiographic analysis of catchment areas. First, results of remote sensing and imaging analysis are applied to calculate the CN values established with the SCS curve number method. Then, the geographic information system is used to integrate and analyze related physiographic data, and lumped HEC-HMS hydrographic models are adopted to establish the hydrographs of the catchment to simulate rainfall and runoff in catchments. Meanwhile, the Storm Water Management Model (SWMM) developed by the National Risk Management Research Laboratory of the US Environmental Protection Agency is applied to perform dynamic hydrographic analysis of rainfall runoff created by a single rain or continuous rainfall in order to solve water quality and quantity problems associated with urban drainage systems. The SWMM can also be applied in conjunction with low-impact development concepts to reduce rainfall runoff. Experiments can be conducted with bioretention systems adopted on campus, and it is possible to understand the changes as well as their benefits before and after addition of concepts associated with impacts of development by making simulations with the SWMM.

The purpose of this study is to evaluate the influence of land use changes in areas of various spatial scales on surface runoff and propose appropriate strategies for reduction of and adaptation to flooding. Initially, satellite images of river basins of different spatial scales are sorted out to analyze land use changes and simulations are made with a hydrologic model to understand land use changes and runoff variations. Then, hot spot analysis is performed to pick out catchments with high concentrations of manmade buildings in each river basin to study the catchments and urban areas. Results of land use surveys and contents of plans for urban and non-urban land use are examined to compare current land use situations and land use changes after implementation of the plans in the future. Rainfall runoff models for different spatial scales are applied to simulate land use changes and runoff variations. In the end, flood adjustment strategies currently adopted in and outside the country are applied in the areas studied to find out the difference in the result of flood reduction.

2. Study Areas

In this study, the Zhuoshui River Basin is chosen to be the area for watershed scale research because the development therein has been simpler and the natural covers are better. As to the area for catchment scale research, since runoff variations caused by land use changes in urban areas will be more obvious, the catchment in the urban area in the river basin is selected after analysis. In the meantime, the urban planning area in Zhushan is chosen to be the object of urban area scale study because the information available is more comprehensive. The spread of spatial scales, including watershed, catchment and urban area scales, are as shown in Fig. 1.

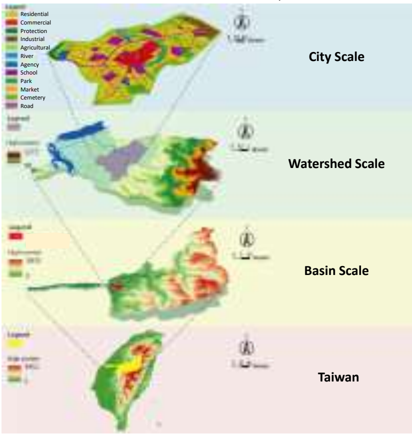


Figure 1 The different spatial scales

3. Methodology

In this study, based on the scales of study areas, different data, models, and time periods are employed for the analysis of land and runoff variations which are concluded in Table 1 and described in the following paragraphs.

Table 1. Study subjects on different scales

	Basin	Watershed	City
Land Data	Land-cover	Land-cover/Land-use	Land-use
Runoff Model	HEC-1	HEC-1	SWMM
Time Period	History	History/Present/Future	Present/Future/Future with LID

3.1 Basin Scale

The Definiens Professional 8 software developed by German Company Definiens Image is applied to perform object-oriented classification in this study. It is helpful in image segmentation and subsequent type-description and interpretation work. In the end, appropriate sample plots for training are selected and marked and also classified into bare land, vegetation, manmade buildings and water bodies. The process of interpretation of land covers in this study is as shown in Fig. 2.

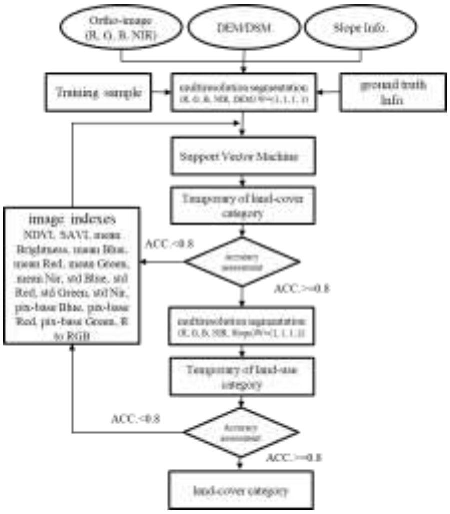


Figure 2 The image interpretation process of landslide

To further analyze land cover type changes, a surface transition matrix is adopted for cross matching to understand the area of each land cover type which has transformed to other types in order to examine the land cover type changes in different periods.

The percentages that land cover types have accounted for in different eras need to be calculated separately in order to understand the spread of spatial change resulted from land use, so that the main areas where land changes have taken place can be inspected through spatial autocorrelation analysis to identify the types of space in which land changes have happened. In this study, the Getis-ord Gi* from the ArcGIS 10 software is used to analyze whether any conspicuous concentration of each land cover type exists in each village.

The basic information of the area studied, such as elevation, rainfall, land use and soil condition, etc., is collected, and a digital terrain model (DTM) is applied to divide the Zhuoshui River Basin into 22 catchments before a geographic information system is adopted to calculate the physiographic and hydrologic parameters of each catchment, including the size of each sub-catchment, lengths of rivers, gradients, SCS curve number (CN) values, etc. Since the type of land use can influence the volume of runoff in a catchment, the curve number method developed by the US Soil Conservation Service is adopted to calculate rainfall losses. In the end, the HEC-1 hydrologic analysis model with which physiographic parameters are easier to control is applied to simulate rainfall runoff to calculate the outflow graphs.

3.2 Watershed Scale

The results of the Second National Land Use Survey conducted by the National Land Surveying and Mapping Center of the Ministry of the Interior in 2008 are adopted as the current land use data. At the same time, information associated with land designated for land use zoning and as non-urban land in urban planning is adopted to be the data on land use in the future.

The HEC-1, with which physiographic parameters are easier to control, is applied to calculate runoff volumes to study the runoff variations caused by land use changes. Since land use is an important variable, the curve number method is chosen to compute rainfall losses in catchment units and the SCS CN values and impervious surface rates are defined as the operating variables.

3.3 City Scale

According to the land use zoning in urban planning in Zhushan, future land use in urban areas is classified to simulate land use changes. The SWMM is applied to divide Zhushan into seven drainage districts in accordance with the town's 2008 Rainwater Sewer System Review and Planning Report. The Horton Equation is applied to calculate rainfall losses, while a geographic information system is adopted to compute related physiographic and hydrologic parameters, such as the size of each sub-catchment, lengths of rivers, gradients, impervious surface rates, etc. to obtain the runoff variations before and after development to understand the impact of land use changes on urban areas.

4. Results and Discussion

4.1 Land-cover and Runoff Changes on the Basin Scale

Table 2 summarizes the areas for land-covers of water, built-up land, bare land, and vegetation in 1998, 2003, 2008, and 2013. The built-up lands show a constantly increase from 1,990 hectares in 1998 to 3,023 hectares in 2013 with a total change ratio of 51.91 %. The bare lands experienced an increase slightly from 8,551 hectares in 1998 to 9,650 hectares in 2003, and a substantial increase to 14,561 hectares in 2008, after which followed by a decrease to 10,347 hectares in 2013, resulting in a total area increase of 21% from 1998 to 2013. In contrast, the area covered by vegetation has a pattern opposite to the bare lands, which decreased constantly from 277,445 hectares in 1998 to 270,717 hectares in 2008, and subsequently increased to 274,707 hectares in 2013. This implies that, for some reason, there exists a switch between the bare lands and vegetation lands from 1998 to 2013.

Table 2. Changes in land-cover areas against time on basin scale

Land-cover Types	1998 (ha)	2003 (ha)	2008 (ha)	2013 (ha)	1998–2013 Change Ratio
Water	12,264	12,284	12,170	12,173	-0.74 %
Built-up Land	1,990	2,792	2,802	3,023	51.91 %
Bare Land	8,551	9,650	14,561	10,347	21.00 %
Vegetation	277,445	275,524	270,717	274,707	-0.99 %

Table 3 display the spatial autocorrelation of artificial structures from 1998 to 2013.

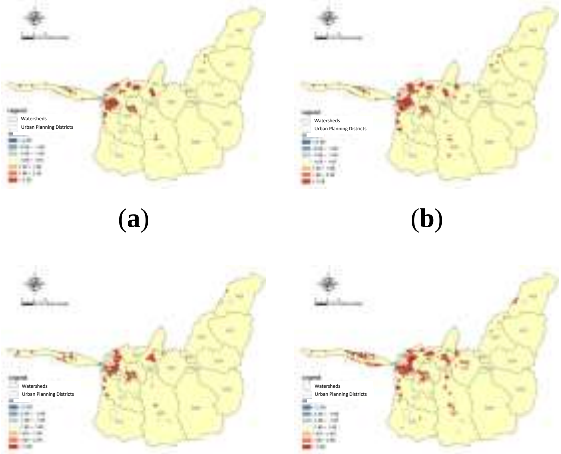
Table 3. Spatial autocorrelation of artificial structures from 1998 to 2013

	1998	2003	2008	2013

Moran's I	0.67	0.76	0.60	0.63
Z-score	94.90	98.20	103.92	118.60
p-value	0.000000	0.000000	0.000000	0.000000

Table 6 lists the Moran's indexes, z-score, and p-value for 1998, 2003, 2008, and 2013. With all Moran's I > 0, *z*-scores > 2.58, and p-values ~ 0, it demonstrates that the artificial structures in Zhoushui river basin are not distributed randomly in space, but highly accumulated.

Figure 2 shows the hotspots of the artificial structures in 1998, 2003, 2008, and 2013, in which grey lines are the boundaries of the 21 watersheds and the red color denotes the grids with higher Gi values.



(**a**) (**b**) (**c**) (**d**)

Figure 2. Hotspots of artificial structures from 2008 to 2013

To initiate the HEC-1 model for runoff simulation, the 24-h rainfall amounts under different return periods are obtained from frequency analysis based on the historical records of Chi-Chi rain station. The 24-h rainfall amounts under 2-y, 5-y, 25-y, 50-y, and 100-y return periods are 204.61, 308.29, 473.97, 543.38, and 612.50 mm, respectively. The rainfall hyetographs served for runoff simulation are determined by the intensity-duration-frequency relationships suggested by Horner and Flynt according to the design handbook published by Water Resource Agency, Taiwan. Summarized in Table 4 are the curve number (CN), the area ratio of impermeability (IMP), and the 100-y peak runoff discharge (Q_p^{100}) on different scales. Overall, no significant changes of CN, IMP, and Q_p^{100} have been found on basin scale. This might be due to the fact that the land-cover are only classified into four groups with 91.5% of vegetation lands, which in a way limits the variation of CN and consequent runoffs. Table 4 also indicates that, because the W20 watershed has higher values of CN and IMP, it generates runoffs of 0.24 cms/ha, much higher than the basin average 0.16 cms/ha.

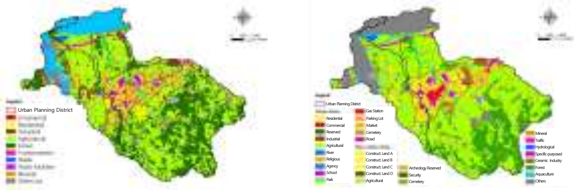
Table 4. Variations of CN, IMP, and Q_p^{100} related to land-cover and land-use changes on different study scales

	Land-cover				Land-use	
	1998	2003	2008	2013	2008	2030
Basin scale *Zhuoshui Basin* (*316,800 ha*)						
CN	43.42	44.17	44.64	44.09	-	-

IMP (%)	0.53	0.62	0.69	0.79	-	-
Q_p^{100} (cms)	48,835	49,350	49,379	49,446	-	-
Watershed scale *W19* (*2,673 ha*)						
CN	51.45	53.18	51.34	52.20	60.55	62.31
IMP (%)	12.91	13.13	14.05	15.00	14.12	18.76
Q_p^{100} (cms)	416	422	417	424	467	486
Watershed scale *W20* (*755 ha*)						
CN	65.38	64.14	63.63	64.92	69.75	76.48
IMP (%)	7.29	8.66	8.79	9.64	13.50	14.73
Q_p^{100} (cms)	182	181	182	183	188	198
City scale *Jushan Dist.* (*422 ha*)						
IMP (%)	-	-	-	-	45.78	61.80
Q_p^{100} (cms)	-	-	-	-	79.62	84.26

4.2 Land-cover, Land-use, and Runoff Changes on the Watershed Scale

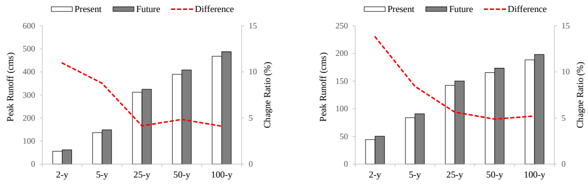
According to the investigation, present (2008) and future (2030) land-use maps on watershed scales for W19 and W20 are shown in Figure 3. The current land-uses are divided into 11 categories while the future land-uses are further refined into 32 categories. Basically, by 2030, large areas of forests will be transferred into agricultural lands and many residential regions will be converted into commercial usages. According to the variations of land-use from 2008 to 2030, the CN values increase from 60.55 to 62.31 and the IMP increase from 14.12% to 18.76% for W19, while the CN values increase from 69.75 to 76.48 and the IMP increase from 13.50% to 14.73% for W20, as listed in **錯誤! 找不到參照來源。**4. However, in the overlay year of 2008, the CN values interpreted from land-use data are much larger than those interpreted from land-cover data, which then lead to different runoff estimations. In this study, the variations of runoff resulted from land-cover and land-use changes are separately discussed.



(**a**) (2008) (**b**) (2030)

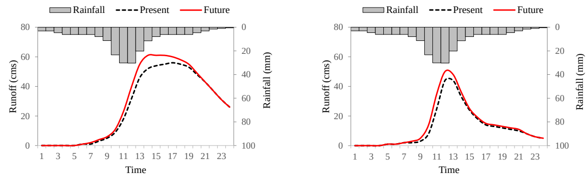
Figure 3. Present and future land-use maps on watershed scale

Figure 4 shows the comparison of present and future runoff peaks under different return periods for W19 and W20, respectively. It is seen that the peak runoffs will be increased in the future under all return periods no matter for W19 or W20. Although the increments of peak runoff are smaller at low return periods, their change ratios are instead larger. The runoff hydrographs under 2-y return period for W19 and W20 are displayed in Figure 5. It shows that future runoff peaks are not only raised but also shifted forward; the integration of runoff hydrographs against time shows that the total increases in runoff volume are 212,400 m3 and 140,400 m3 for W19 and W20, equivalent to 85 and 56 standard swimming pools, respectively. This could put a non-negligible extra risk of flooding if additional flood control measures are not taken.



(**a**) W19 (**b**) W20

Figure 4. Present and future runoff peaks on watershed scale



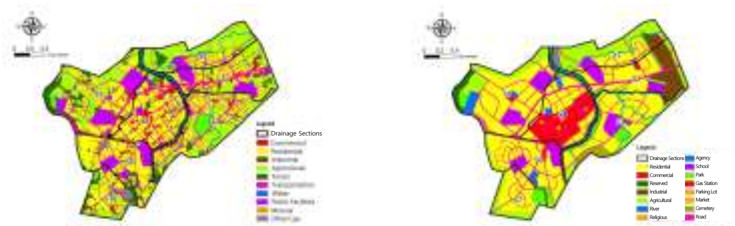
(**a**) W19 (**b**) W20

Figure 5. Runoff hydrographs under 2-y return period for watersheds W19 and W20

4.3 Land-use and Runoff Changes on City Scale

According to the sewer system report for Jushan in 2008, the Jushan District is divided into seven drainage sections as shown in Figure 6 and the land-use maps for these sections at present and in the future are compared in Figure 7. The figure shows that, by 2030, the commercial area will be greatly expanded and mostly concentrated in S4, a large industrial block will be developed at the borders of S1 and S2, and the residential areas are going to increase in almost every sections. Figure 8 indicates that the IMP for all the seven sections increase simultaneously, from 23%~69% at present to 36%~ 88% in the future, in which the S1 has the highest increase ratio of 58%. The variations of average IMP and Q_p^{100} on city scale are also listed in **錯誤! 找不到參照來源。**4, which shows that this increase of IMP will raise Q_p^{100} from 79.62 cms to 84.26 cms by 2030.

Figure 6. Drainage divisions on city scale



(**a**) (2008) (**b**) (2030)

Figure 7. Present and future land-uses on city scale

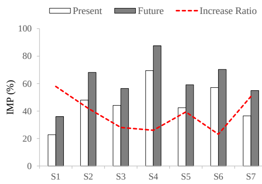


Figure 8. Comparison between present and future IMP on city scale

In response to the rising of flood risk in the future, various LID measures are designed and incorporated into the SWWM model on city scale to evaluate their effectiveness of runoff reduction. To reduce public resistance, the LID measures are installed on government-owned lands or facilities. Some lands or facilities like cemeteries, sewage treatment plants, and gas stations are ruled out for LID because of their particular usages. **錯誤! 找不到參照來源。**5 summarizes the areas of different land-uses and the area ratios in which different LID facilities are installed. Using the LID control editor built in SWMM model, parameters of LID facilities are given by different ground layers including surface, soil, and storage as summarized in Table 6. The surface and soil layers are porous that allow water to pass through; the storage layer contains water within the soil void and when the storages are full, excessive water will overflow. In this study, no underdrains are considered. According to the area occupation of each LID facility, the IMP for each drainage section are adjusted for runoff simulation.

Table 5. Area ratios of different LID facilities with respect to land-uses

Land-use types	Area (ha)	Bio-retention Cell (%)	Rain Garden (%)	Green Roof (%)	Infiltration Gutter (%)	Permeable Pavement (%)
School	29.03	-	10	30	15	5
Park	11.82	90	-	-	-	-
Agency	7.17	35	-	50	-	-
Social	7.17	-	-	30	15	5
Market	0.95	-	10	80	-	-
Tourist	0.66	35	-	50	-	-
Parking Lot	0.58	-	35	-	-	-
Plaza	0.29	-	35	-	-	-

Table 6. Parameters for LID facilities

		Bio-retention Cell	Rain Garden	Green Roof	Infiltration Gutter	Permeable Pavement
Surface	Berm Height (m)	0.15	0.15	0.04	-	-
Soil	Thickness (m)	0.45	0.45	0.10	-	0.25
	Porosity	0.25	-	0.30	-	0.25
Storage	Thickness (m)	0.15	-	-	0.10	0.45
	Void Ratio	0.25	-	-	0.25	0.25

Shown in Figure 1 are the simulated runoff peaks and runoff volumes for different return periods under three land-use scenarios: present, future, and future with LID. At high return periods, the increased amounts are slightly larger than those at low return periods, but not obvious. After introducing the LID facilities, Figure 1(a) shows that the runoff peaks for 2-y and 5-y return periods will be effectively reduced to a level even less than the present condition. However, for the return periods of 25, 50, and 100 years, it is surprising to see that the introduction of LID instead lead to slight increases in runoff peaks. In fact, this phenomenon has been discovered in previous papers, but, unfortunately, without satisfactorily explanations. Fortunately, Figure 1(b) shows that the LID does help to reduce runoff volumes no matter at high or low discharges. From the case study above, it is certain to say that the introduction of LID benefits flood mitigation at low discharges, but as discharge increases, the effectiveness of LID becomes trivial or unfavorable that should work in conjunction with other flood mitigation measures.

(a) Runoff Peak (b) Runoff Volume

Figure 1. (a) Runoff peak and (b) runoff volume for different return periods under land-use scenarios of present, future, and future with LID

Table summarized the runoffs on watershed scale simulated by HEC and those on city scale simulated by SWWM, in which the V_{W19}, V_{W20}, V_{city} are the runoff volumes generated by W19, W20, and Jushan District, respectively. It is seen that, at low return periods, the V_{city} has a larger share in the total watershed runoff $V_{W19} + V_{W20}$ than at high return periods. Through the cross-examination of the runoff results produced by HEC-1 and SWWM, one may say that, for runoff analysis, concomitant usage of different hydrological models on different scales is practical if the same geological data are applied. Overall, at 2-y return period, the LID can reduce about 10% of the city runoff volume, equivalent to 2% of the watershed runoff volume and 0.02% of the basin runoff volume.

Table 7. Comparison of runoffs simulated under different land-use scenarios on watershed and city scales

		2-y	5-y	25-y	50-y	100-y
Present	V_{W19} $(10^3\ m^3)$	2,250	4,428	8,622	10,105	11,840
	V_{W20} $(10^3\ m^3)$	1,022	1,811	3,136	3,654	4,190
	V_{city} $(10^3\ m^3)$	731	1,137	1,793	2,069	2,345
	$V_{city}/(V_{W19}+V_{W20})$ (%)	22	18	15	15	15
Future	V_{W19} $(10^3\ m^3)$	2,462	4,788	9,050	10,606	12,366
	V_{W20} $(10^3\ m^3)$	1,163	1,994	3,348	3,884	4,446
	V_{city} $(10^3\ m^3)$	762	1,175	1,839	2,118	2,396
	$V_{city}/(V_{W19}+V_{W20})$ (%)	21	17	15	15	14
Future with LID	V_{city} $(10^3\ m^3)$	687	1,061	1,790	2,072	2,347

5. Conclusion

Come along with urbanization, analyzing the runoff variations caused by land-cover and land-use changes is very important for flood mitigation reference. However, this analysis should not be conducted merely on city scale but should also on larger scales because a city is part of a watershed or river basin. In this study, the land and runoff variations resulted from urbanization are analyzed on basin scale (large), watershed scale (medium), and city scale (small) for Zhuoshui River Basin, Taiwan. Based on the scale sizes, different data and models are employed for land interpretation and runoff simulation in history, at present, and in the future (Table 1). Overall, the patterns of land-runoff changes due to urbanization are discovered on the basin scale; the discrepancy raised from the usage of different geological data and hydrological models are evaluated on the watershed scale; and the impacts of LID facilities on flood reduction in response to urbanization are quantified on the city scale. The research findings on different scales are summarized as below:

1.On the basin scale, the increase in built-up area is less than 1% of the entire river basin that has no influence on the variation of simulated runoff.

2. On the watershed scale, discrepancies in runoff estimations are found because the values of CN and IMP interpreted from land-use data are much larger than those interpreted from land-cover data. Thus, mixed usage of satellite-interpreted land-cover data and manual-investigated land-use data is not recommended for hydrological analysis. The concomitant usage of HEC-1 and SWMM shows no contradiction in runoff results.

3. On the city scale, the LID facilities effectively reduce the runoff volumes for all return periods in local scale. However, runoff peak is another story. For high return periods, the introduction of LID instead slightly increases the runoff peaks. Thus, LID approaches are better regarded as local flood mitigation measures in low-discharge conditions.

References

1. Nirupama, N.; Simonovic, S.P. Increase of flood risk due to urbanization: a Canadian example. Nat. Hazards. 2007, 40, 25–41
2. Saghafian, B.; Farazjoo, H.; Bozorgy, B.; Yazdandoost, F. Flood intensification due to changes in land use. Water Resour. Manag. 2008, 22, 1051–1067.
3. Liu, Y.B.; Gebremeskel S.; De Smedt F.; Hoffmann L.; Pfister L. Predicting storm runoff from different land-use classes using a geographical information system-based distributed model, Hydrol. Process. 2006, 20, 533–548.
4. Shi, P.J.; Yuana Y.; Zhenga J.; Wanga J.A.; Gea Y.; Qiua, G.Y. The Effect of Land Use/Cover Change on Surface Runoff in Shenzhen Region, China, CATENA. 2007, 69, 31–35.
5. Shalaby, A.; Tateishi, R. Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt. Applied Geography. 2007, 27, 28–41.
6. Lambin, E.F.; Baulies, X.; Bockstael, N.E. Land-use and land-cover change implementation strategy. Stockholm: IGBP Report No. 48 and IHDP Report No. 10, 2002.
7. Engman, E.T.; Gurney, R.J. Remote Sensing in Hydrology. London: Chapman and Hall, London. 1991.
8. Guan, M.; Sillanpää, N.; Koivusalo, H. Modelling and assessment of hydrological changes in a developing urban catchment. Hydrol. Process. 2015, 29, 2880–2894..
9. Mattikalli, N.M.; Devereux, B.J.; Richards, K.S. Prediction of river discharge and surface water quality using an integrated geographic information system approach. Int. J. Remote Sens. 1996, 17, 683–701.
10. Li, H.; Ding, L.; Ren, M.; Li, C.; Wang, H. Sponge city construction in China: a survey of the challenges and opportunities. Water, 2017, 9, 594
11. Álvarez Martínez J.M.; Suárez-Seoane, S.; De Luis Calabuig, E. Modelling the risk of land cover change from environmental and socio-economic drivers in heterogeneous and changing landscapes: The role of uncertainty. Landscape Urban Plan. 2011, 101, 108-119.
12. Xian, G.; Crane, M.; Su, J. An analysis of urban development and its environmental impact on the Tampa Bay Watershed, J. Environ. Manage. 2007, 85, 965–976.
13. Morita, H.; Hoshino, S.; Kagatsume, M.; Mizuno, K. An Application of the Land-Use Change Model for the Japan Case Study Area, IIASA Interim Report IR-97-065. 1997
14. Serra, P.; Pons, X.; Saurı´, D. Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors, Appl. Geogr. 2008, 28, 189–209
15. U.S. Army Crops. of Engineers. (USACE). Hydrologic Modeling System: HEC-HMS Technical Reference Manual. Davis, CA: Hydrologic Engineering Center. 2000.