

Full Length Research Paper

Impacts of urban growth on flood hazards in Makkah City, Saudi Arabia

Khaled A. Al-Ghamdi¹, Ramze A. Elzahrany¹, Meraj N. Mirza^{1,2} and Gomaa M. Dawod^{1,3*}

¹Geography Department, Umm Al-Qura University, Makkah, Saudi Arabia.

²Center of Research Excellence in Hajj and Omrah, Umm Al-Qura University, Makkah, Saudi Arabia.

³Survey Research Institute, Egypt.

Accepted 23 January, 2012

Flash floods are the most dangerous type of natural disasters in arid regions, such as Saudi Arabia. The effects of urban growth, witnessed between 1990 and 2010, in Makkah city, Saudi Arabia, on runoff volume and peak discharge are investigated using the curve number (CN) flood-modelling methodology. Shapefiles of residential areas are compiled and integrated in a unique geographic information system (GIS) environment. Datasets of geological structures, soil types, and a digital elevation model (DEM) have been collected and utilized. Peak discharges have been computed on the wadi scale, while the total flood volume have been estimated on the sub-basin scale for residential sub-basins in order to get a detailed view of urbanization impacts on flood hazards. The results obtained show that the residential regions of Makkah city have been increased, over the period 1990 to 2010, by 197%, while the total flood volumes have been enlarged by 248%. The spatial distribution of high-flood urban regions is mapped. Furthermore, the results show significant positive correlations between urbanization and both peak discharge and flood volume. Accordingly, these findings should be taken into account in future urbanization, sustainable development and flood management plans of Makkah metropolitan area.

Key words: Flood hazards, rainfall-runoff, curve number (CN), geographic information system (GIS), Saudi Arabia.

INTRODUCTION

The dispersed development along highways or surrounding a city and in rural countryside is called urban sprawl. Geomatics technologies, such as remote sensing (RS) and geographic information system (GIS), furnish exceptional technical tools for urban modelling and planning. Extensive studies have been carried out to investigate the utilization of RS images, in particular, in the assessment of land use and land cover changes over time (Prakasam, 2011; Arunachalam et al., 2011; Liu et al., 2011; Kioko and Okello, 2011). In addition, GIS has been widely employed as a valuable precise tool in monitoring urban sprawl for land use planning (Kelarestaghi and Jeloudar, 2011; Su et al., 2011;

Antipova et al., 2011). The integration of both GIS and RS presents an exceptional technique in monitoring and prediction of urban growth (Park et al., 2011).

Generally, floods are natural returning hydrological phenomena that significantly affect human lives. The hazards of flash floods, chiefly in urban regions, are vital from both human settlement and economical perspectives. Recently, the estimation of flood hazardous impacts and the development of GIS-based flood inundation maps have been considered a crucial demand. For example, Sagala (2006) carried out a detailed vulnerability assessment study to investigate physical flood hazards, particularly buildings' damages, in a residential area depending upon a mobile GIS. Fernandez and Lutz (2010) described a GIS-based research produced flood hazard maps for two cities in Argentina based on a multi-criteria design analysis. Park

*Corresponding author. E-mail: dawod_gomaa@yahoo.com.

and Hur (2011) have utilized GIS for the development of flood simulation system for Namgang watershed, South Korea. In addition, a similar methodology was proposed and tested in Georgia, USA (Qi and Altinakar, 2011). Hagen et al. (2011) presented a simple methodology for developing a nation-wide flood hazard maps in Afghanistan as an example of developing countries.

In the Kingdom of Saudi Arabia (KSA), a great attention has been paid recently to the issue of flood assessment and flood hazards estimation. For example, Al Saud (2010) has utilized GIS and RS to assess the hazardous impacts of the flash flood that occurred in November 2009 in Jeddah city. It was concluded that flood-urbanization relationship should be considered in order to avoid further urban expansions in areas under flood risk. Dawod et al. (2011) developed a GIS-based process to quantify the flood parameters, for example, peak discharge and runoff volume, and in Makkah city based on the US National Resources Conservation Service (NRCS)'s flood modelling method (known also as the curve number (CN) methodology. Moreover, Subyani (2011) investigated the flood probability for arid basins in Makkah administrative area. Dawod and Koshak (2011) developed NRCS-based unit hydrographs for the six basins within Makkah metropolitan area as a tool for rainfall-runoff modelling and flood management. Sen (2008a) proposed modified Snyder unit hydrographs for flood modeling in Wadi Baysh, a major Wadi in the southwestern part of KSA.

With the development of urbanization, flood disaster in urban areas threatens regional sustainable development. Human encroachment on urban regions made these urban communities more vulnerable to floods, which necessitates continuous updating of flood management strategies (Zheng and Qi, 2011). Land use plays a critical role in the hydrological behavior of basins, and changing land uses may influence the local hydrological cycle. The land use changing scenarios should be continuously integrated with flood hazard maps (Barredo and Engelen, 2010).

The relationship between urban growth and floods has been investigated in many countries. Paquier (2010) emphasized that the eventual change in flood discharges could be one among other factors of the changes in flood risks in the Agly River, city of Marseille, France. That study showed that flood vulnerability increased a lot because of the development of urbanization mainly in connection with recreation activities or because of the proximity of a large city. Olang and Furst (2011) studied the impacts of historical land cover changes witnessed between 1973 and 2000 on the hydrologic response of the Nyando River Basin, Kenya. The study utilized RS images, land cover change maps, a digital elevation model (DEM), and soil datasets of the basin. Their results revealed significant and varying increases in the runoff peak discharges and volumes within the basin. The study carried out by Ronfort et al. (2011) reported that the

runoff volume is affected by the crop types in an agricultural watershed in upper Normandy, France. Elfert and Bormann (2011) have also studied the relation between land use and runoff in Germany. Douglas et al. (2007) pointed out that the land cover throughout London city continues to be greatly modified by urbanization, changing the response to rainfall and flood peaks and extent are becoming higher. Furthermore, it has been confirmed that the main driving force of increased flood risk is found in new urban developments in flood-prone areas in the Pordenone province in northern Italy (Barredo and Engelen, 2010). A GIS-based research showed that runoff might be increased, due to the expected urbanization in Lai Nullah basin in Pakistan, by 52 to 100% (Ali et al., 2011). In the great lake region in USA, the land use changes increased the total runoff by 10 to 40% over the period 1950 to 2000 (Mao and Cherkauer, 2009). Similarly, Im et al. (2009) reported that changes of 10% non-urban area to urban area, between 1980 and 2000, has resulted in 5.5% increase in total runoff within the Gyeongancheon watershed in Korea. Significant increase in total runoff was also reported due to the land use changes in the Golestan watershed, Iran (Saghafian et al., 2008). Another study, in New York city USA, has emphasized that suburban development and its associated impervious surfaces accelerate the transport of storm runoff (Burns et al., 2005). Moreover, Pizzuto et al. (2007) have studied the impacts of land use and climate changes on riverbeds in Maryland, USA. The results of a study in the Los Angeles metropolitan region have shown the potential increase in flood risk for various watersheds as a result of growing population. It was found that urban watersheds, on average, convert 90% of rainfall to runoff, whereas the non-urban forested watersheds retain 25% of the rainfall (Sheng and Wilson, 2009). In addition, Sherief (2008) has concluded that land use and road networks are key factors affect flood runoff volume and path in south Sinai, Egypt. The study carried out by Wang et al. (2010) presented a GIS-based process for assessing lake impairment status and identifying which human disturbances have the greatest impact on each lake for all lakes in the state of Michigan, USA. Moel et al. (2011) showed that the total amount of urban area, in the Netherlands, that can potentially become inundated due to floods from the sea or main rivers has increased six-fold during the 20th century, and may double again during the 21st century.

The current research aims to investigate and quantify the relationship between urban sprawl and flood hazards in Makkah city.

STUDY AREA

Makkah city is located in the south-west part of KSA, about 80 km east of the Red Sea (Figure 1). It extends from longitudes 39° 35' E to 40° 02' E, and from latitudes

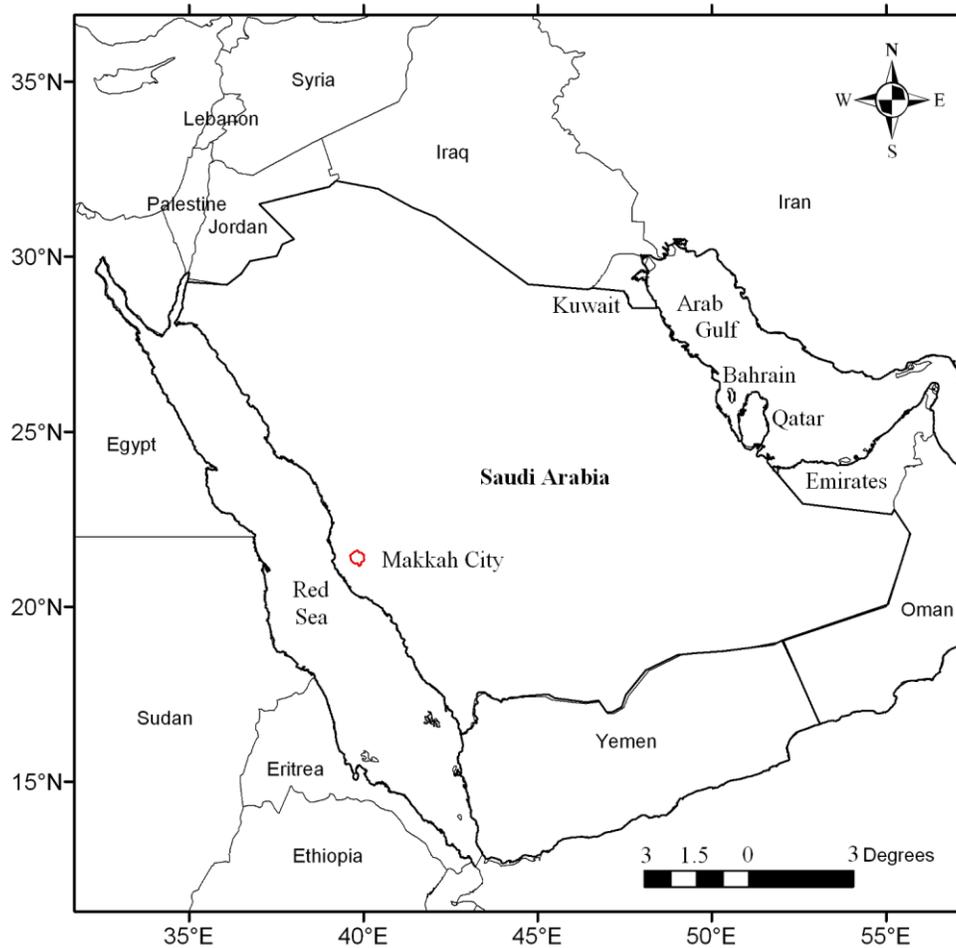


Figure 1. Location of the study area.

21° 09' N to 21° 37' N. Makkah city is a unique city for Muslims all over the world, since it contains the holly mosque. From a religious point of view, a Muslim should perform pilgrimage (called Hajj, which means visiting Makkah in specific days in the year) once in his/her life. Thus, several millions Muslims gather in Makkah yearly. In addition, Muslims prefer to perform a religious tourism plane, called Omarh, to Makkah all over the years. This is an important factor to be considered in analysing the urban growth of this city. Moreover, the topography of Makkah is complex in nature, and several mountainous areas exist inside its metropolitan area. That is also a vital element in investigating the spatial pattern of Makkah sprawl and its impacts on flood hazards.

On a national level, precise flood assessment is considered as an important demand in the Makkah metropolitan area due to the unexpected nature of rainfall that often produces hazardous flash floods. It worth mentioning that the southwest part of KSA contains almost 60% of the volume of wadi flow, particularly in the terrain situated between the Red Sea coast and the

adjacent mountains (Nouh, 2006). The annual rain over Makkah city, for a period extending from 1966 to 2010, varies from 3.8 to 318.5 mm, with an average of rainfall equals 102.6 mm (Figure 2). Due to the complexity of Makkah's topography, flash floods occur periodically with significant variations in magnitude. Mirza and Ahmed (2001) reported that the extreme flood type is repeated with a return period of 46 years, while a second-order flood takes place occasionally with a return period of 33 years, and a low-dangerous flood comes about every 13 years. Using the magnitude of the annual rain average (which equals 101.2 mm) as a rain intensity factor might not be optimum in flood estimation process. The rain intensity of a single extreme storm may exceed the annual rainfall average for a year. For example, the 1969 storm records showed that the rain intensity reaches 107.5 mm/h during the first 10 min of that storm. Based on records of a single rainfall station, this extreme storm resulted in a runoff volume of more than 41 million m³ in the central area of Makkah city, with results of severe damages and human loses (ibid). The topography of the

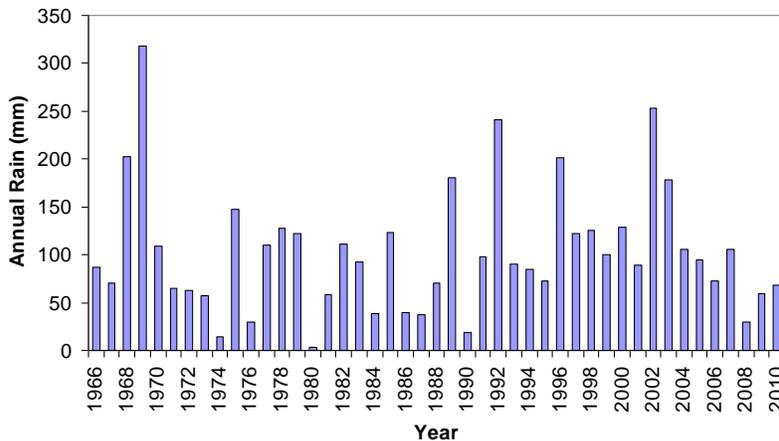


Figure 2. Annual rainfall in Makkah city from 1966 to 2010.

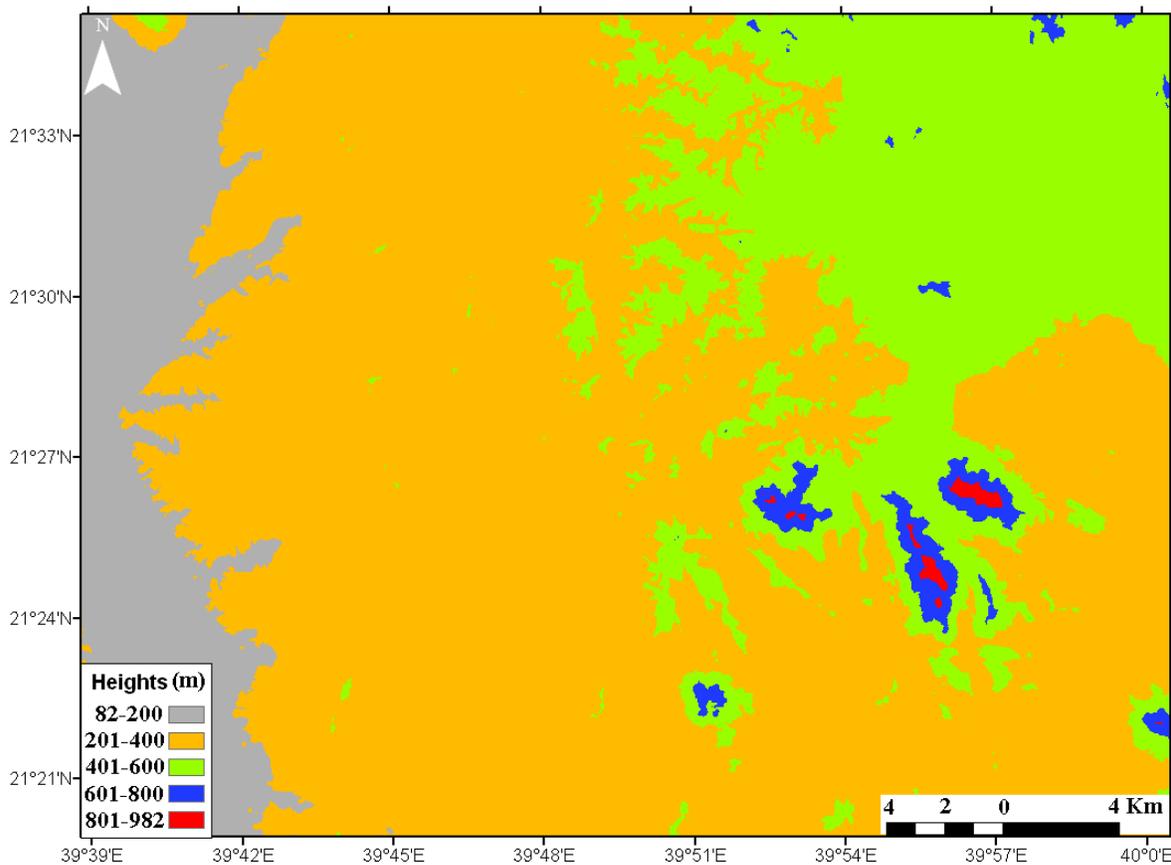


Figure 3. Terrain heights, above mean sea level, in Makkah city.

Makkah metropolitan area is complex, where several mountainous regions exist within the urban boundaries of the city. Terrain heights in Makkah (Figure 3) range from 82 to 982 m above sea level (Mirza et al., 2011). It is known that the growth in Makkah city spreads out along

the valleys and stays away from the mountainous areas for economical reasons. It worth mentioning that almost 50% of Makkah's geology contains igneous rocks, mainly granite, that massively increase the development costs in mountainous areas.

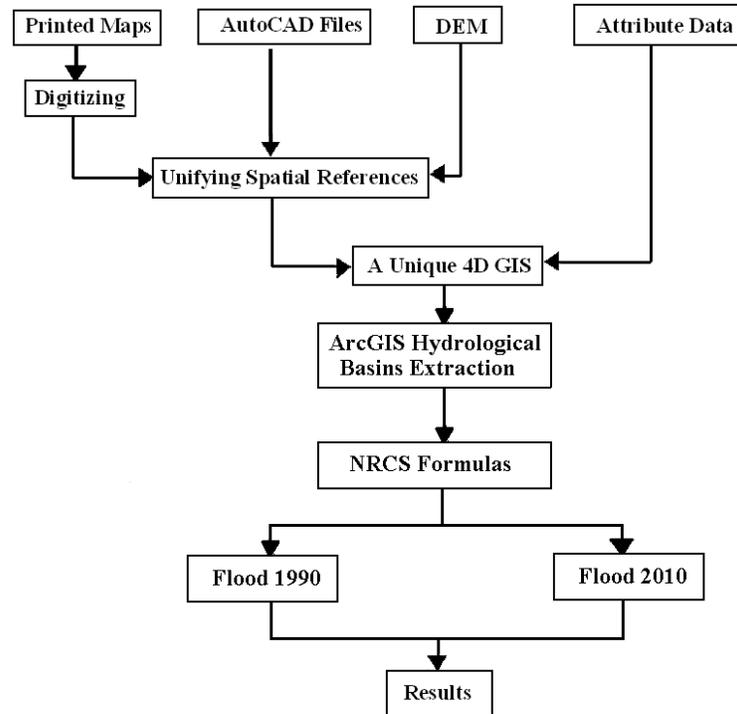


Figure 4. Summary of the employed processing procedures.

MATERIALS AND METHODS

The compiled available spatial datasets constitute of two categories for 1990 and 2010. The first element consists of 105 cadastral maps in AutoCAD format for 1990, obtained from the Makkah governorate. The second constituent consists of a land use map developed by the Saudi geological survey authority dated 2010. Additionally, a national 5-m resolution DEM for the study area (Figure 3) has been obtained from King Abdulaziz City of Sciences and Technology (KACST). The Arc GIS software (v. 10) has been used in the present study to combine all obtainable data in a unique environment. The processing phase includes (Figure 4): rectifying the printed maps, digitizing shapefiles for residential, converting AutoCAD files to GIS shapefiles, unifying the spatial reference frames for all datasets, estimating flood characteristics, particularly the flood volume, through the curve number methodology, and comparing the attained quantitative for 1990 and 2010. The ArcGIS and ArcHydro programs were utilized to extract the main hydrological basins in the study area, and their sub-basins. The spatial analysis tools have been utilized to assign the CN value of each sub-basin based on its geological, soil, and land use properties. Visual basic application (VBA) was utilized to compute sub-basins' flood characteristics, for 1990 and 2010, within the attribute table of GIS shapefiles.

Countless approaches have been proposed globally for estimating flood characteristics based on topographic and morphometric properties of hydrological regions. The NRCS, formerly known as the soil conservation service (SCS), might be considered as the most widely-utilized flood modelling methodology. It utilizes geological information to assign a unique CN coefficient value for each area that will be further used to estimate the surface runoff depth and the peak discharge magnitude. The NRCS method is utilized in engineering design and flood management projects in several countries (Masoud, 2011; Al-Jabari et al., 2009; Adebayo et al., 2009; Elaji, 2010; Xianzhao and

Jiazhu, 2008; Gul et al., 2009), and particularly in USA (US ACE, 2004; US DoT, 2002). The basic formulas of the NRCS approach are (US NRCS, 1986):

$$Q = (P - 0.2 S)^2 / (P + 0.8 S) \quad (1)$$

Where,

Q = depth of direct runoff (mm)

P = depth of precipitation for a specific return period (mm)

S = maximum potential retention (mm):

$$S = 25.4 (1000 / CN) - 10 \quad (2)$$

Tables providing values of CN, for soil and geological types, are presented in several hydraulic literatures (Sen, 2008b: 165). Table 1 presents some of these CN values.

$$qp = qu A Q \quad (3)$$

Where,

qp = peak discharge (m³/s)

A = drainage area (km²)

Q = depth of runoff (mm)

qu = unit peak discharge (m³/s/km²/mm) that can be interpolated from a specific charts (e.g. US NRCS, 1986) or computed from corresponding tables (US DoT, 2002: 5-28).

$$Q_T = Q A \quad (4)$$

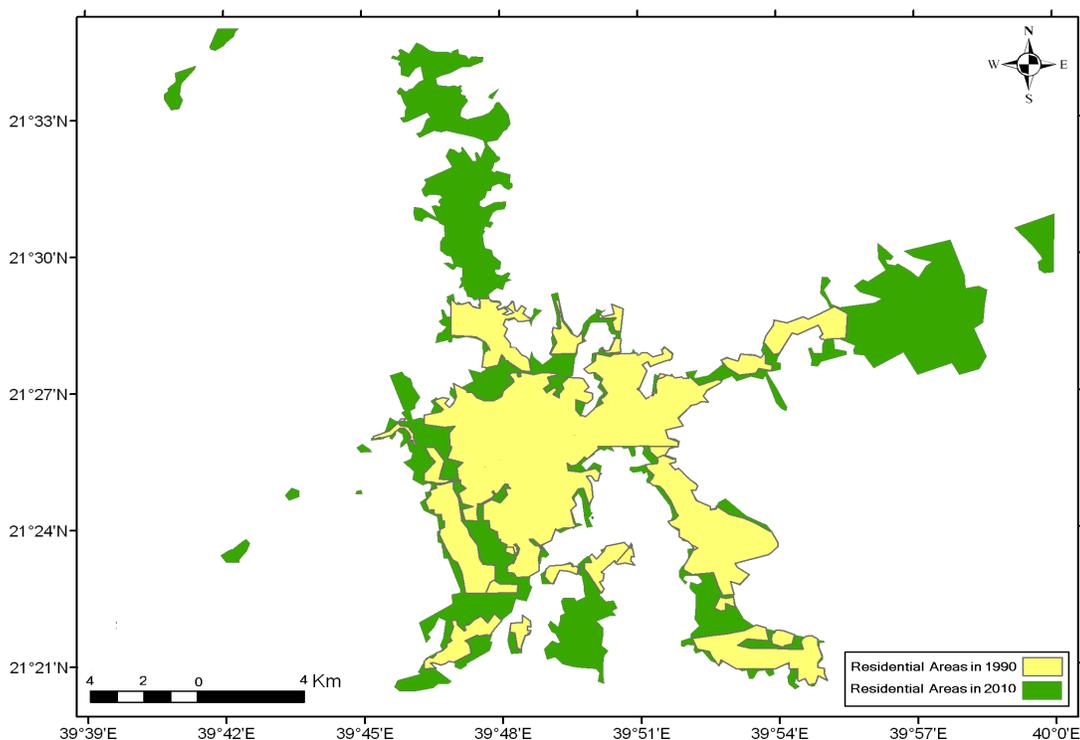
Where Q_T = Flood volume (m³)

$$Q_P = qu A \quad (5)$$

Table 1. Examples of runoff CN values.

Cover type	Hydrological soil types			
	A	B	C	D
Fully developed urban areas (vegetation established):				
Good condition; grass cover on 75% or more of the area	39	61	74	80
Fair condition; grass cover on 50 to 75% of the area	49	69	79	84
Poor condition; grass cover on 50% or less of the area	68	79	86	89
Streets and roads:				
Paved with curbs and storm sewers (excl. right-of-way)	98	98	98	98
Gravel (incl. right-of-way)	76	85	89	91
Industrial districts (72% average impervious)	81	88	91	93
Commercial and business areas (85% average impervious)	89	92	94	95

Where: Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted, Group B soils have moderate infiltration rates when thoroughly wetted, Group C soils have low infiltration rates when thoroughly wetted, Group D soils have high runoff potential and low infiltration rates when thoroughly wetted. After US NRCS, 1986.

**Figure 5.** Urban sprawl patterns of Makkah city for 1990 and 2010.

Where Q_p = peak discharge (m^3/s).

RESULTS AND DISCUSSION

In the first processing step, shapefiles of Makkah metropolitan area for 1990, and 2010 have been integrated in a GIS project (Figure 5). The total residential

area has been computed and found to be 80.021 and 157.564 km^2 for 1990 and 2010 respectively. This means that the residential areas in Makkah city have been grown by about 97% from 1990 to 2010 (with a 4.8% annual rate). The most important reason behind the huge urban sprawl in mid-20th century might be the enormous national income expansion due to oil exploration in the Gulf region. This economical enlargement caused an

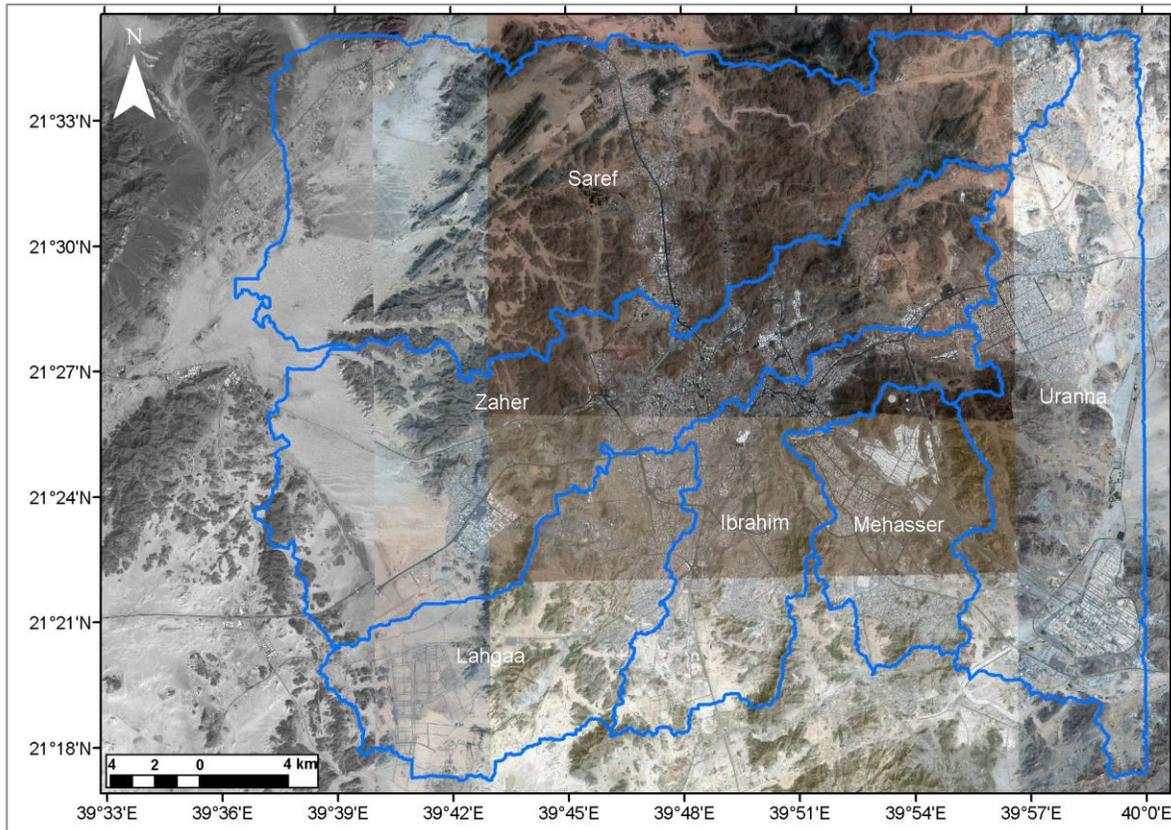


Figure 6. The main basins in the Makkah metropolitan area.

Table 2. Statistics of morphometric quantities of the main basins in the Makkah metropolitan area.

Item	C1	C2	C3	C4	C5	C6
Basin area (km ²)	252.7	122.3	74.3	109.9	360.6	200.2
Basin Premier (km)	134.6	69.13	50.23	89.09	134.76	102.03
Length of main stream (km)	42.48	23.64	16.50	29.70	48.55	38.13
Relief ratio (m/km)	12.6	14.1	40.4	25.9	13.0	18.7

Where C1: Zaher wadi, C2: Ibrahim wadi, C3: Mehasser wadi, C4: Lahгаа wadi, C5: Sareef wadi; and C6: Uranna wadi.

urban development revolution not just in Makkah city but also in almost all towns within Saudi Arabia. Secondly, the official planning rules and governmental authority have been started in 1955 in order to regulate the urban development of Makkah city (HAMDD, 2004).

Secondly, six main hydrological basins have been identified, in Makkah city, with areas ranging from 74.3 to 360.6 km², and lengths of their main streams varying from 16.50 to 48.55 km (Figure 6). Table 2 presents the statistics of some of the hydrological parameters of these basins. A comprehensive GIS-based morphometric analysis of these basins has been carried out (Koshak and Dawod, 2011). A number of 60 sub-basins have been recognized within these six basins.

Furthermore, the NRCS method has been performed for the available data of Makkah metropolitan area to compute the peak discharge value for the six basins for the 1990 and 2010 datasets. The return period has been chosen, herein, as 50 years, for which the rainfall intensity (P in Equation 1) has been estimated, by applying the Log Pearson III statistical analysis, as 200 mm/h (Dawod et al., 2011).

The first stage of the flood hazard estimation has been performed on the main-basin level. In this phase, the peak discharges have been computed (Equation 5) for the six main basins of the study area for both 1990 and 2010. The differences, in peak discharges of six basins, range from 11 to 88 m³/s. In a relative sense, this is an

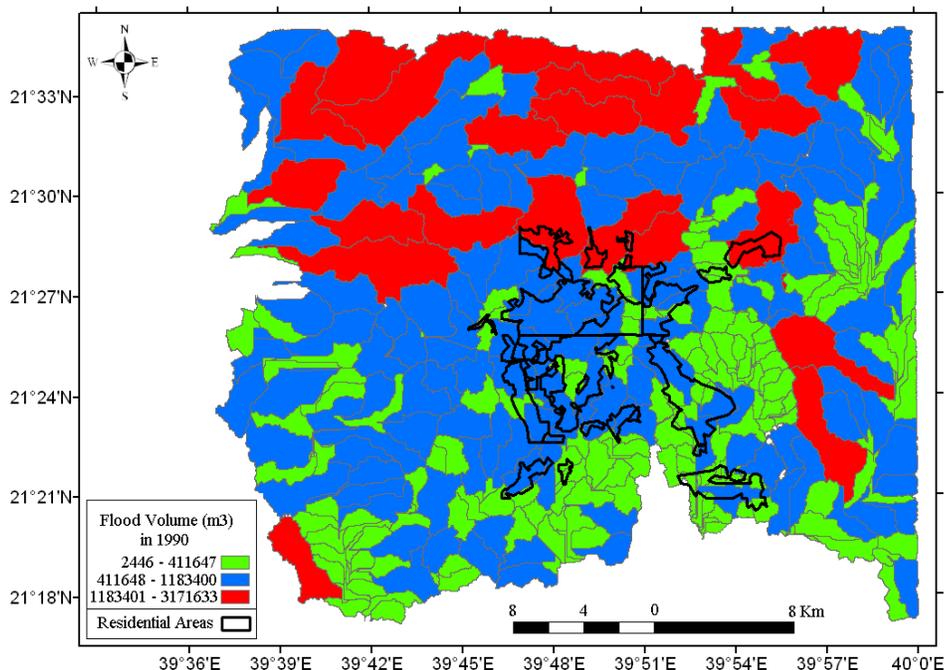


Figure 7. Floods over residential areas in 1990.

Table 3. Statistics of floods over residential areas in 1990 and 2010.

Item	1990	2010
Number of sub-basins contain residential areas	25	64
Total area of residential areas (km ²)	80.021	157.564
Minimum flood volumes (m ³)	79,623	45,487
Maximum flood volumes (m ³)	1,809,701	2,928,694
Total flood volumes (m ³)	11,849,980	41,282,085

increase of 1.1 to 3.5% relative to the 1990 peak discharge values. Such results only provide an overall view of the inter-relationship between urbanization and flood hazards. The mean increase of flood peak discharge, 1.8%, might not be the optimum mathematical element to revalue the impact of urban growth in Makkah city. It is worth mentioning that the urban areas only constitute 7.3 and 14.4% out of the total area of the six watersheds (which is 1095 km²). Hence, their effects on the peak-discharge increase are small, but they give a general indication that urbanization increases flood hazardous impacts.

In the second phase of data processing, the total flood volumes have been computed on the sub-basin scale, only for those sub-basins which contain residential areas. A total of 25 sub-basins, that include residential areas in 1990, have been identified within the study area (Figure 7). Table 3 presents the statistical properties of the flood properties in residential areas in 1990. The area of these

sub-basins range from 0.478 to 10.663 km², with a sum of 71.587 km². The flood volumes of these sub-basins have been estimated (equation 4) for 1990 and found to vary from 79.6 to 1809.7 thousands m³ with a total of 11849.9 thousands m³.

Then, utilization of the 2010 datasets revealed that there are 64 sub-basins that include residential areas (Figure 8). Table 3 also presents the attained statistical properties of the 2010 flood properties. The area of these sub-basins range from 0.223 to 18.569 km², with a sum of 157.564 km². The flood volumes of these sub-basins have been estimated for 2010 and found to vary from 45.5 to 2928.7 thousands m³ with a total of 41282.1 thousands m³.

Comparing the results of flood estimation for both 1990 and 2010 reveals critical points. First, the residential areas of Makkah city have been increased, over the twenty year period, from 80.0 to 157.6 km², with 197% increase (with an annual rate of 9.8%). Second, the total

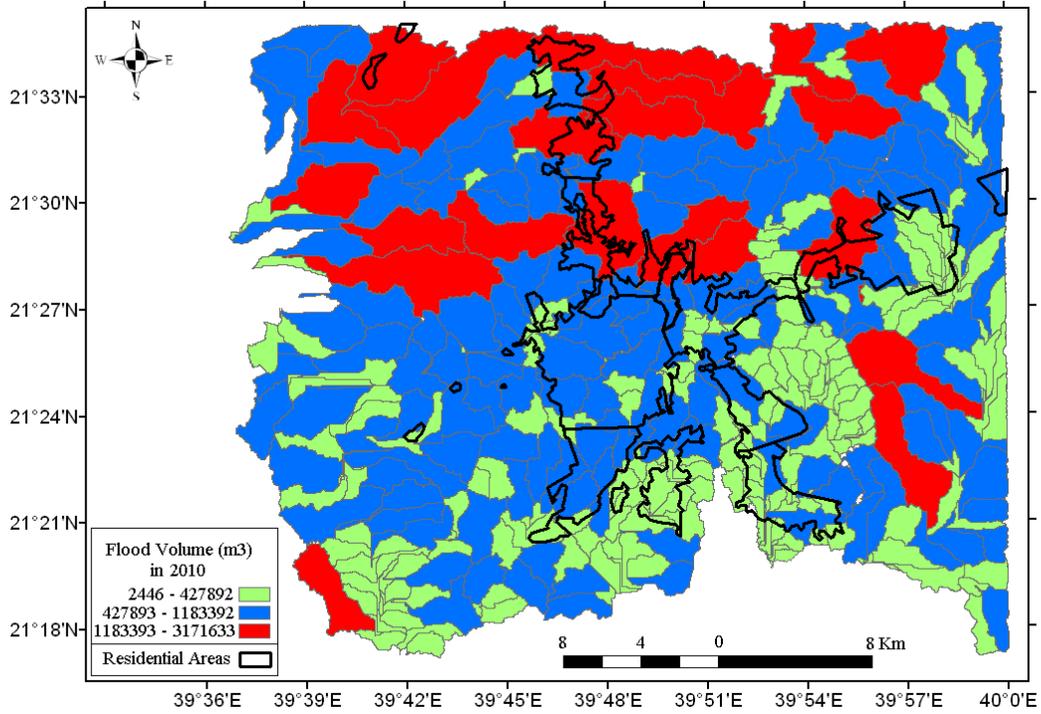


Figure 8. Floods over residential areas in 2010.

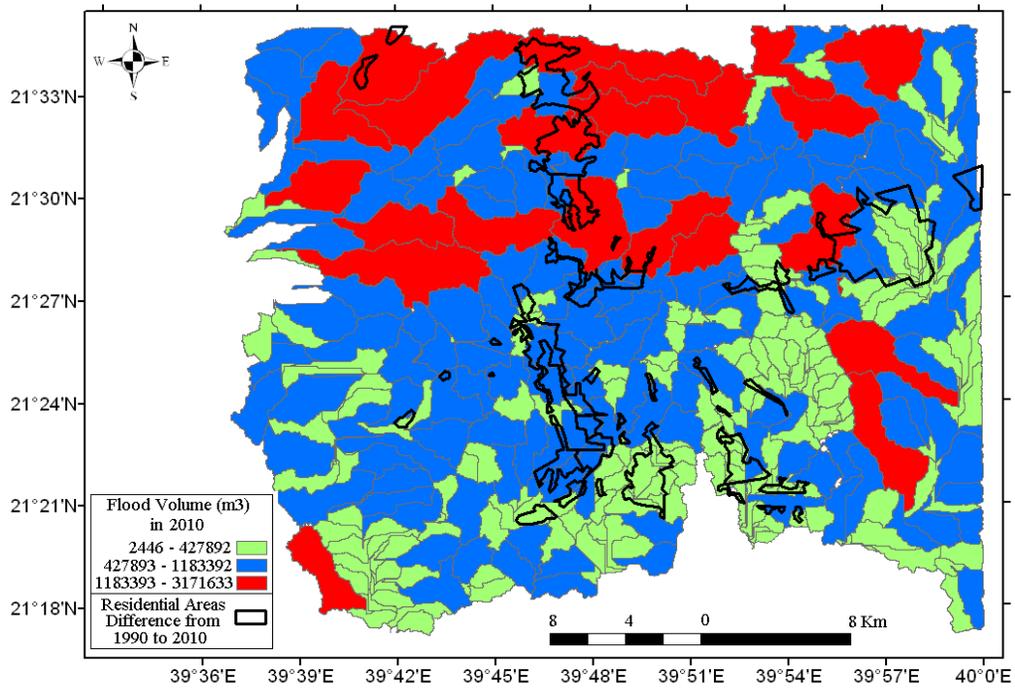


Figure 9. Floods over new residential areas built between 1990 and 2010.

flood volumes have been increased from 11.8 to 41.3 million m³, i.e. 248%. The spatial distribution of the new

residential areas (built between 1990 and 2010) is depicted in Figure 9. It can be seen that there are several

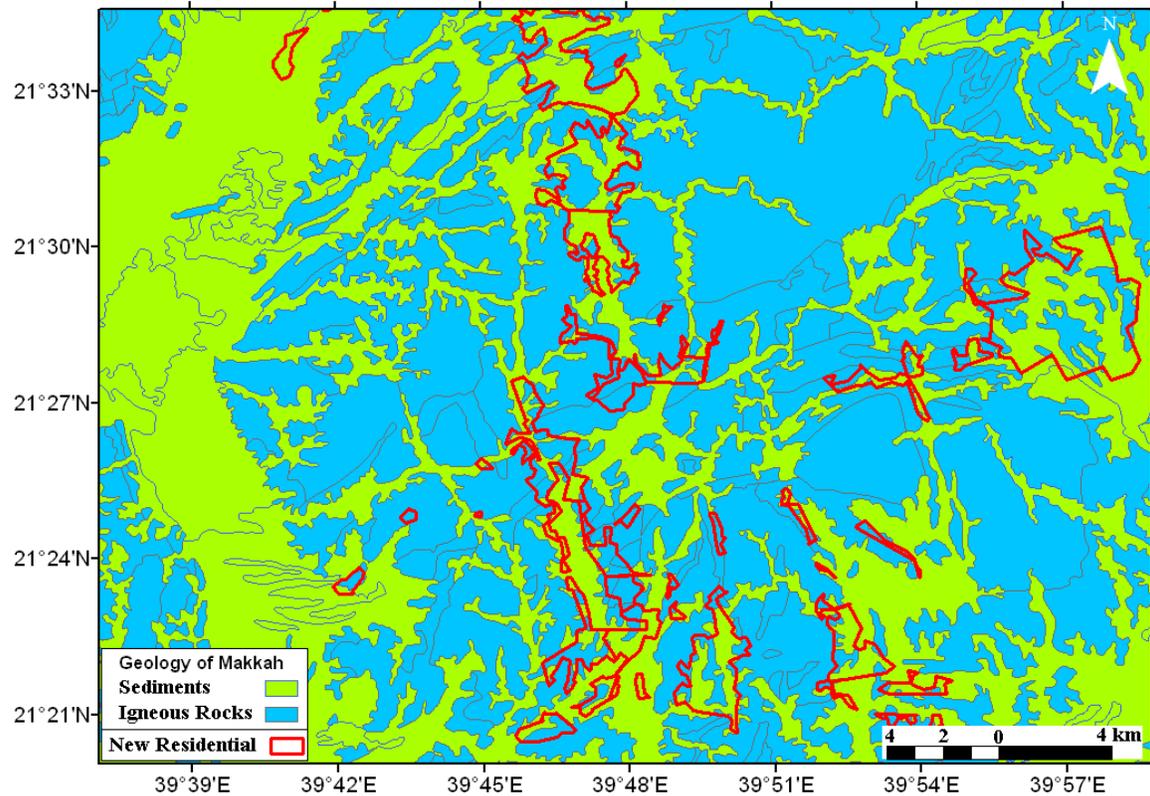


Figure 10. Geology of new residential areas built between 1990 and 2010.

new areas, particularly in the north of Makkah city, located in high-flood sub-basins. It has been found that even though the new residential areas within the Saref wadi constitute only 26.5% of the total urbanization, they are responsible for 51.8 % of the flood increase. Furthermore, it has been found that most of the new residential areas have been established on sediment soils (Figure 10). From an economical point of view, that geological type is cost-effective than constructing building on solid igneous rock geology. However, that urbanization significantly decreases the permeability of the soil and, thus, leads to a crucial increase in hazardous water surface runoff. For example, the CN of sediment geology type equals 76, while it equals 98 for paved residential areas (Sen, 2008b; US NRCS, 1986). These two factors might be the major reasons for severe augmentation of flood volume in the Makkah metropolitan area.

Lastly, a correlation analysis has been carried out on the wadi level for residential area increase, peak discharge increase, and total flood volume changes in the six main basins in the study area (Figure 6) between 1990 and 2010. The relationship between these three factors is depicted in Figure 11, and results of correlation are tabulated in Table 4. Figure 11 shows a positive proportional trend, in general, between the increase of residential areas, peak discharge, and flood volume. The

correlation, between urbanization and peak discharge augmentation equals 0.70, and that between urbanization and total flood volume increase equals 0.51. These values might be considered as a significant positive correlation between urbanization and enlarged flood hazards.

Conclusions

The NRCS curve number approach has been used in this study, utilizing available topographic, geological, and land use datasets, to estimate flood hazards in Makkah city in 1990 and 2010. The results showed that the residential regions of Makkah city have been increased by 197%, while the total flood volumes have been enlarged by 248%. Two factors might be considered possible reasons leading to the rise in significant flood hazard. First, establishment of new residential areas in regions that already posse high flood impacts. Second, building up new suburban areas on sediment soil significantly decreases the permeability of the soil and thus, leads to a crucial increase in hazardous water surface runoff. Results showed significant positive correlations between urbanization and both peak discharge and flood volume.

Such findings should be taken into account in future urbanization and flood management plans of Makkah

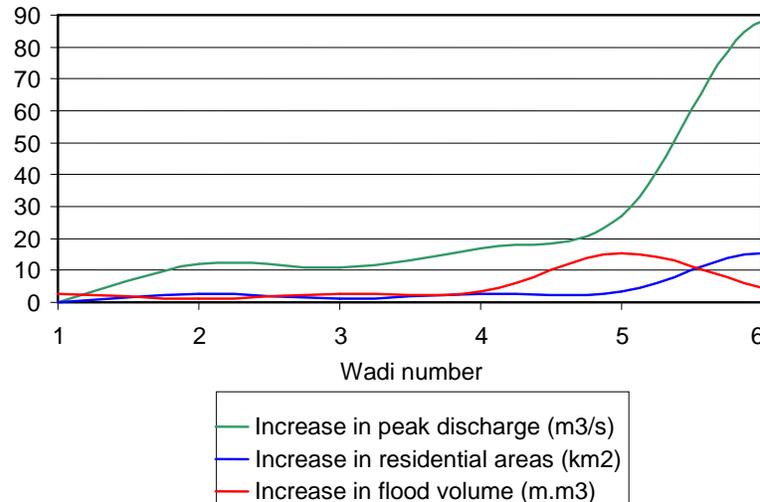


Figure 11. Variations of peak discharges, residential areas, and total flood volumes from 1990 to 2010.

Table 4. Correlation values.

	A	B	C
A	1		
B	0.70	1	
C	0.51	0.94	1

Where: A = Increase in residential areas (km²), B = Increase in peak discharge (m³/s), and C = Increase in flood volume (m.m³).

city, Saudi Arabia.

ACKNOWLEDGMENT

The authors would like to acknowledge the partial financial support offered by the Center of Research Excellence in Hajj and Omrah, Um Al-Qura university, Saudi Arabia (Project PR12/2011).

REFERENCES

- Adebayo W, Solomon O, Ayanniyi M, Sikiru F (2009). Evaluation of synthetic unit hydrograph methods for the development of design storm hydrographs for Rivers in South-West, Nigeria. *J. Am. Sci.*, (5)4: 23-32.
- Ali M, Khan S, Aslam I, Khan Z (2011). Simulation of the impacts of land-use change on surface runoff of Lai Nullah Basin in Islamabad, Pakistan, *Landscape and Urban Planning*. 102: 271-279.
- Al-Jabari S, Abu Sharakh M, Al-Mimi Z (2009). Estimation of runoff for agricultural watershed using SCS curve number and GIS, *Proceedings of the thirteenth International Water Technology Conference*, Hurgada, Egypt. 1213-1229.
- Al Saud M (2010). Assessment of flood hazard of Jeddah area 2009, Saudi Arabia. *J. Water Res. Prot.*, 2: 839-847.
- Antipova A, Wang F, Wilmot C (2011). Urban land uses, socio-demographic attributes and commuting: A multilevel modeling approach, *Applied Geography*. 31: 1010-1018.
- Arunachalam S, Maharani K, Chidambaram S, Prasanna M, Manivel M, Thivya C (2011). A study on the Land use pattern change along the coastal region of Nagapattinam, Tamil Nadu. *Int. J. Geom. Geosci.*, (1)4: 700-720.
- Barredo J, Engelen G (2010). Land use scenario modeling for flood risk mitigation, *Sustainability*. 2: 1327-1344.
- Burns D, Vitvar T, McDonnell J, Hassett J, Duncan J, Kendall C (2005). Effects of suburban development on runoff generation in the Croton River basin, New York, USA. *J. Hydrol.*, 311: 266-281.
- Dawod G, Koshak N (2011). Developing GIS-based unit hydrographs for flood management in Makkah metropolitan area, Saudi Arabia, *J. Geogr. Inform. System.* (3)2: 153-159.
- Dawod G, Mirza M, Al-Ghamdi K (2011). GIS-based spatial mapping of flash flood hazards in Makkah city, Saudi Arabia, *J. Geogr. Inform. System.* (3)3: 217-223.
- Douglas I, Kobold M, Lawson N, Pasche E, White I (2007). Characterization of urban streams and urban flooding, In: *Advances in urban flood management*, Ashley, R. (ed), Taylor and Francis group, London, UK. pp. 29-58.
- Elaji A (2010). Applications of Geographic Information Systems to construct databases of morphometric characteristics and their hydrologic meanings in Yalamlam basin (in Arabic), MSc thesis, Umm Al-Qura University, Makkah, Saudi Arabia.
- Elfert S, Bormann H (2011). Simulated impact of past and possible future land use changes on the hydrological response of the Northern German lowland 'Hunte' catchment, *J. Hydrol.*, (383): 245-255.

- Im S, Kim H, Kim C, Jang C (2009). Assessing the impacts of land use changes on watershed hydrology using MIKE SHE, *Environmental Geology*, 57: 231-239.
- Fernandez D, Lutz M (2010). Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis, *Engineering Geology*, 111: 90-98.
- Gul G, Harmancıoğlu N, Gul A (2009). A combined hydrologic and hydraulic modeling approach for testing efficiency of structural flood control measures, *J. Nat. Hazard*. DOI 10.1007/s11069-009-9464-2.
- Hagen E, Schroder J, Lu X, Teufert J (2011). Reverse engineered flood hazard mapping in Afghanistan: A parsimonious flood map model for developing countries, *Quaternary International*, 226: 82-91.
- HAMDD (Higher Authority for Makkah District Development) (2004) Master planning of Makkah city till 2028, Technical report (in Arabic), Makkah, Saudi Arabia.
- Kelarestaghi A, Jeloudar Z (2011). Land use/cover change and driving force analyses in parts of northern Iran using RS and GIS techniques, *Arab J. Geosci.*, 4: 401-411.
- Kioko J, Okello M (2011). Land use cover and environmental changes in a semi-arid rangeland, Southern Kenya, *J. Geogr. Regional Plan.*, (3)11: 322-326.
- Koshak N, Dawod G (2011). A GIS morphometric analysis of hydrological basins for flood management within Makkah Metropolitan Area, Saudi Arabia. *Int. J. Geom. Geosci.*, 2(2): 502-511.
- Liu D, Li B, Liu X, Warrington D (2011). Monitoring land use change at a small watershed scale on the Loess Plateau, China: applications of landscape metrics, remote sensing and GIS, *Environmental Earth Science*, DOI 10.1007/s12665-011-1051-7.
- Mao D, Cherkauer K (2009). Impacts of land-use change on hydrologic responses in the great lakes region, *J. Hydrol.*, 374: 71-82.
- Masoud A (2011). Runoff modeling of the wadi systems for estimating flash flood and groundwater recharge potential in Southern Sinai, Egypt. *Arab J. Geosci.*, 4: 785-801.
- Mirza M, Ahmed B (2001). Winter weather and climate conditions in Makkah (in Arabic), *Geographic Messages*, 253, Kuwait Geographic Association, Kuwait.
- Mirza M, Dawod G, Al-Ghamdi K (2011). Accuracy and relevance of digital elevation models for geomatics applications - A case study of Makkah municipality, Saudi Arabia, *Int. J. Geom. Geosci.*, (1)4: 803-812.
- Moel H, Aerts J, Koomen E (2011). Development of flood exposure in the Netherlands during the 20th and 21st century, *Global Environmental Change*, 21: 620-627.
- Nouh M (2006). Wadi flow in the Arabian Gulf states, *Hydrological Process*, 20: 2393-2413.
- Olang L, Furst J (2011). Effects of land cover change on flood peak discharges and runoff volumes: model estimates for the Nyando River Basin, Kenya, *Hydrological Processes*, 25: 80-89.
- Paquier A (2010). Flood studies and effects of climate change: two examples. Presented in the International Workshop on Impacts of Global Warming from Hydrological and Hydraulics Issues, March 16, Kyoto, Japan.
- Park J, Hur Y (2011). Development and application of GIS based K-DRUM for flood runoff simulation using radar rainfall, *J. Hydro-environ. Res.*, doi:10.1016/j.jher.2011.05.005.
- Park S, Jeon S, Kim S, Choi C (2011). Prediction and comparison of urban growth by land suitability index mapping using GIS and RS in South Korea, *Landscape and Urban Planning*, 99: 104-114.
- Pizzuto J, Moglen G, Palmer M, Nelson K (2007). Two model scenarios illustrating the effects of land use and climate change on gravel riverbeds of suburban Maryland, USA, A technical Report, University of Maryland, USA.
- Prakasam C (2011). Land use and land cover change detection through remote sensing approach: A case study of Kodaikanal taluk, Tamil nadu. *Int. J. Geom. Geosci.*, (1)2: 150-158.
- Qi H, Altınakar M (2011). A GIS-based decision support system for integrated flood management under uncertainty with two dimensional numerical simulations, *Environmental Modelling and Software*, 26: 817-821.
- Ronfort C, Souchère V, Martin P, Sebillotte C, Castellazzi M, Barbottin, Meynard J, Laignel B (2011). Methodology for land use change scenario assessment for runoff impacts: A case study in a north-western European Loess belt region (Pays de Caux, France), *Catena*, 86: 36-48.
- Saghafian B, Farazjoo H, Bozorgy B, Yazdandoost F (2008). Flood intensification due to changes in land use, *Water Resources Management*, 22:1051-1067.
- Sagala S (2006). Analysis of flood physical vulnerability in residential areas, Case study: Naga city, the Philippines, Master thesis, International Institute for Geo-information Science and Earth Observation, The Netherlands.
- Sen Z (2008a). Modified hydrograph method for arid regions, *Hydrological Process*, 22: 356-365.
- Sen Z (2008b). *Wadi Hydrology*, CRC Press.
- Sheng J, Wilson J (2009). Watershed urbanization and changing flood behavior across the Los Angeles metropolitan region, *Nat. Hazard*, 48: 41-57.
- Sherief Y (2008). Flash floods and their effects on the development in El-Qaa plain area in south Sinai, Egypt, PhD Dissertation, University of Mainz, Germany.
- Su S, Jiang Z, Zhang Q, Zhang Y (2011). Transformation of agricultural landscapes under rapid urbanization: A threat to sustainability in Hang-Jia-Hu region, China. *Appl. Geogr.*, 31: 439-449.
- Subyani A (2011). Hydrologic behavior and flood probability for selected arid basins in Makkah area, western Saudi Arabia. *Arab J. Geosci.*, 4: 817-824.
- US ACE (US Army Corps of Engineers) (2004). Physical stream assessment.
- US DoT (US Department of Transportation) (2002). Highway hydrology manual, Publication No. FHWA-02-001.
- US NRCS (US National Resources Conservation Services) (1986). Urban hydrology for small watersheds, Technical Manual TR55.
- Wang L, Wehrly K, Breck J, Kraft L (2010). Landscape-based assessment of human disturbance for Michigan lakes. *J. Environ. Manage.*, 46: 471-483.
- Xianzhao L, Jiazhu L (2008). Application of SCS model in estimation of runoff from small watershed in Loess plateau of China. *J. Chinese Geogr. Sci.*, (18)3: 235-241.
- Zheng Z, Qi S (2011). Potential flood hazard due to urban expansion in the Karst mountainous region of North China, *Regional Environmental Change*, 11: 439-440.