DIGITAL EARTH: QUANTIFYING URBAN LANDSCAPE CHANGES FOR IMPACT ANALYSIS

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Abstract

This study is to quantify land cover changes over time in order to analyze the impacts of human disturbances and climate factors on urban landscapes. The study area is Kansas City metropolitan area, USA. The study investigated both "dry-landscapes" – urban impervious surface and "wet-landscapes" – urban wetlands in order to fully understand the coupling effects of human built-up activities and precipitation variations. For the dynamics of dry-landscapes, we classified multi-year Landsat images to map impervious surface change in relation to other land cover types at a metropolitan level. Based on the classified maps, we calculated relevant landscape metrics, including land patch density index and largest patch index of land covers, in order to better understand landscape change mechanism. The study reveals that in the recent decades urban built-up activities have greatly increased impervious surfaces and resulted in urban sprawling in the study area. To understand the variation of wet-landscapes, high-resolution SPOT images were classified to map urban wetlands and other relevant land cover types at finer scales. The mapped wetlands were analyzed in relation to precipitation conditions and impervious surface changes. The results suggest that urban wetland area changes were correlated with short-term precipitation conditions at a regional level, while the built-up activities have affected wetlands in some locations at fine scales.

Keywords: Digital earth, remote sensing, landscape metrics, urban wetlands, urban built-up, precipitation

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1. INTRODUCTION

As an important aspect of global change, urban landscape transformation has increasingly become a major issue facing many metropolitan areas. To effectively understand this trend and associated consequences, geospatial techniques including remote sensing and Geographic Information Systems (GIS) have been increasingly used to monitor and quantify urban landscape changes, resulting in digital earth surfaces at a regional scale (*e.g.* Da Costa and Cintra, 1999; Chen *et al*., 2000; Masek *et al*., 2000; Ryznar and Wagner, 2001; Lo and Yang, 2002; Yang, 2002; Ji *et al*., 2006 ; Herold , *et al*., 2008; Thapa and Murayama, 2009; Du, *et al*., 2010). Observations suggest that in many metropolitan areas, urban landscapes might have been shaped mainly by human developments while precipitation could have also played a role. Thus, to assess urban landscapes as related to specific driving factors, identifying appropriate indicators is the key. Previously, investigations commonly used the urban built-up as a key indicator in understanding the patterns and processes of human decisions and disturbances. While this approach can effectively identify significant shifting of urban environment under human influences, it lacks the capability to examine the effects of environmental variation like precipitation on shaping urban physical landscapes at a regional scale.

In our study, we propose to generate the “wet” indicator - urban wetlands, as opposed to the “dry” indicator - urban built-up areas, to investigate the coupling effects of human activities and regional precipitation on urban landscapes. This is because surface waters are more sensitive to both human-induced disturbance and climate variation than the urban built-up indicator (roads, buildings, *etc.*). The study area is in the metropolitan Kansas City, USA, which has experienced significant urban development in the past decades as identified by previous studies (*e.g.* Ji, *et al*., 2006). Our study has the following objectives: (1) Understanding urban landscape change trend at a regional scale and (2) Detecting urban wet-landscapes as an indicator of the coupling effects of human development and regional precipitation variations. The following approaches were taken to address these objectives: (a) Quantifying regional landscape alterations using satellite image classification and landscape metrics; (b) Detecting urban wet-landscape dynamics at fine scales using high resolution satellite imagery; and (c) Analyzing the factors that might have impacted urban wet-landscapes.

2. STUDY AREA

The Kansas City metropolitan area is located in the central United States and centered along the eastern boundary of Kansas and the western boundary of Missouri. Rolling hills and open plains represent a general topography of the area. The predominant land cover is vegetation that primarily consists of grasslands, with forests and cropland. The metropolitan area covers 7 counties that include more than 10 major cities. The area witnessed significant population and economic growth for the past century, especially in the recent decades.

3. METHDOLOGY AND ANALYSIS

3.1 Quantifying Regional Landscape Alterations

(1) Multi-temporal landscape change detection

In this effort, Landsat images covering the Kansas City metropolitan area were obtained for the years 1972, 1979, 1985, 1992, 1999, and 2001. The images from mid-July to mid-August were chosen for better land cover detection during the growing season. The data sources for 1972 and 1979 were Landsat-1 and Landsat-3 Multispectral Scanner (MSS), respectively. The data sources for 1985 and 1992 were Landsat-5 Thematic Mapper (TM), and for 1999 and 2001 images were Landsat-7 Enhanced Thematic Mapper (ETM+). The 1972 and 1979 images have a spatial resolution of 57 m × 57 m (nominal resolution), the 1985 image 28.5 m × 28.5 m (nominal resolution), and the 1992, 1999, and 2001 images 30 m × 30 m.

The images were classified using the supervised maximum likelihood classification method. We identified four major types of land cover: built-up area, surface waters, forestland, and non-forest vegetation (Fig. 1). The "built-up" class depicts residential areas of single houses and apartment buildings, shopping centers, industrial and commercial facilities, highways and major streets, and associated properties and parking lots, which represent urban impervious surfaces. “Waterbody” consists of lakes, reservoirs, rivers, and isolated or riparian surface waters, many of which fall into wetland classification (Cowardin *et al.*, 1979). The "non-forest vegetation" class includes grasslands, brush land, and cropland.

The general patterns of land cover change were identified at the metropolitan level. As summarized in Table 1, the results of satellite image classification (Fig. 1) suggest that the metropolitan area has experienced significant landscape alterations mainly due to urban expansion. In the study area, the built-up lands increased over the past three decades at an average rate of 4.25% per year, and the non-forest vegetation cover bore the major burden of urbanization. The forestland cover remained relatively unchanged at the metropolitan level. Interestingly, the surface water class doubled its aerial extent in the region in the same period of time, although this land cover class was presumably expected to be reduced by increased built-up activities. These observations raised the following research questions: (1) Were there any environmental factors, most likely precipitation variation, that might have jointly or even predominantly shaped wetland landscapes along with human developments? (2) If these environmental factors were significant, how did the coupling effect of human-activities and environmental variation alter urban landscapes spatially and temporally?

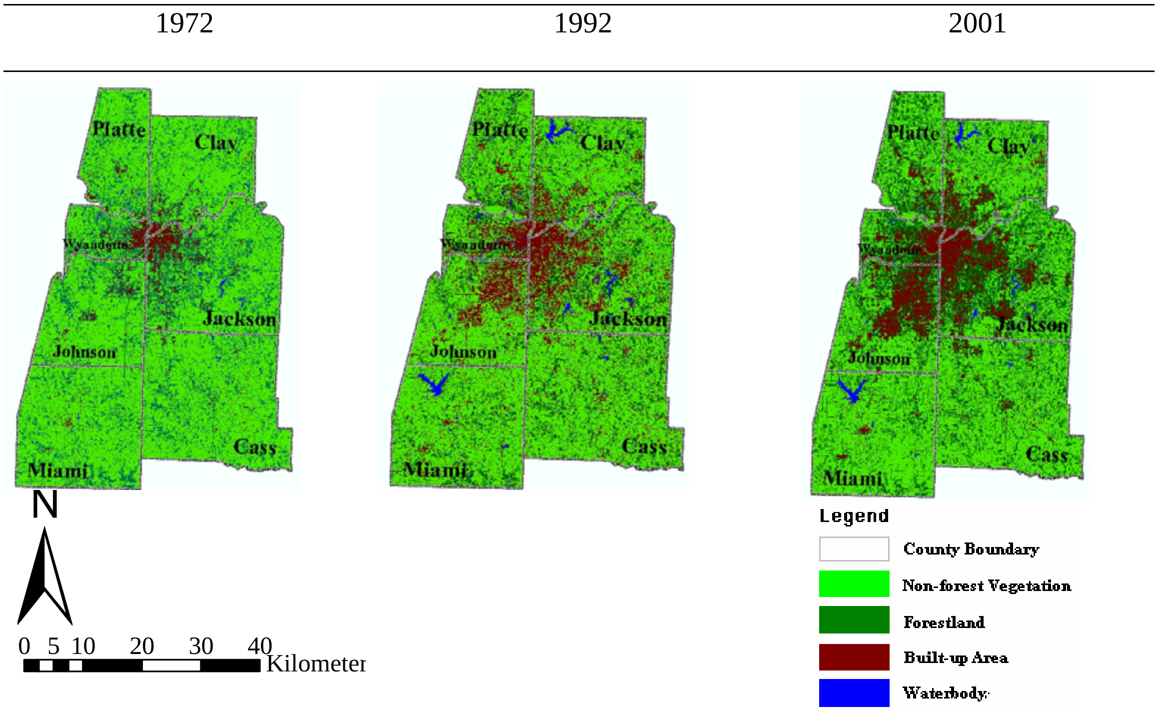


Fig. 1. Selected classified Landsat images showing significant urban land cover changes in the study areas. In the past three decades, both urban built-up area (in red) and urban surface waters (in blue) approximately doubled their coverage by percentage.

Table 1. Percentages of land cover types obtained from classified satellite images in the Kansas City Metropolitan area.

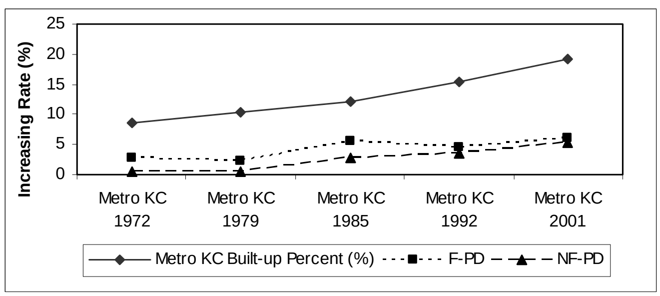
	1972	1979	1985	1992	1999	2001
Built-up area	**8.65%**	**10.38%**	**12.03%**	**15.41%**	**18.69%**	**19.19%**
Forest	**16.36%**	**16.44%**	**16.81%**	**16.58%**	**16.71%**	**17.36%**
Non-Forest	**73.93%**	**71.96%**	**69.06%**	**66.03%**	**62.70%**	**61.24%**
Surface Water	**1.05%**	**1.22%**	**2.10%**	**1.99%**	**1.90%**	**2.21%**

(2) Quantifying urban landscapes using landscape metrics

To better quantify urban landscape changes, we calculated landscape metrics using the FRAGSTATS program (McGarigal and Marks, 1995) based on remote sensing classification data. The metrics at the landscape level include the index of patch density (PD) of the built-up land cover and the largest patch index (LPI) of the non-forest vegetation (NF-LPI) and the forestland (F-LPI). The PD equals the number of patches of the corresponding land cover type divided by total area of interest. It is a measure of land cover pattern of a class type. The LPI at the class level quantifies the percentage of total land area comprised by the largest patch. As such, it is a measure of dominance of a land cover type.

The derived landscape metrics were analyzed to reveal the change patterns of landscapes due to urban development. At the metropolitan level, the non-forest vegetation and the forestland became more fragmented as the result of the built-up activities over the period of study. This trend of landscape change was demonstrated by the positive correlation between the built-up area (%) and the index of patch density of the non-forest vegetation and the forestland (NF-PD and F-PD) (Figure 2-a). Fig. 2-b shows that as the built-up coverage increased, the largest patch index of the non-forest vegetation (NF-LPI) decreased while the LPI of the forestland (F-LPI) remained relatively stable. This suggests that the non-forest vegetation experienced the decrease and fragmentation in a large range of patch sizes while large forest areas (patches) were less impacted in the course of urban development in the region.

(a)



(b)

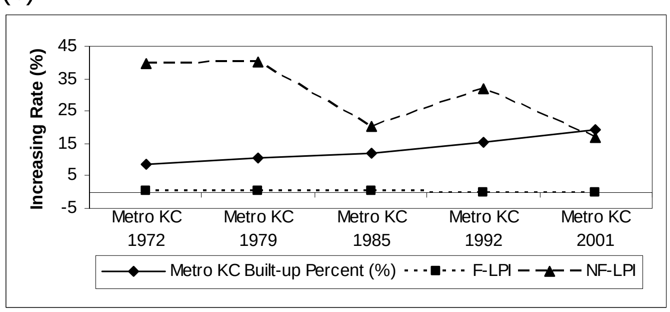
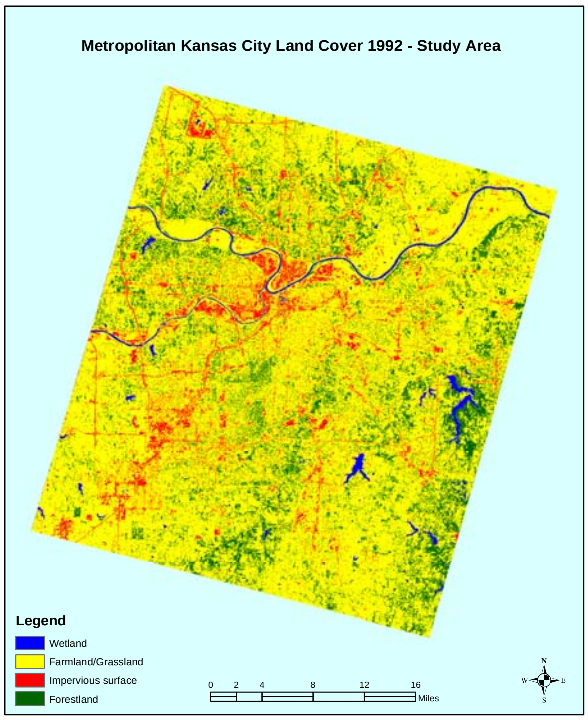


Fig. 2. (a) The correlation between the built-up area (%) and the patch density of the non-forest vegetation (NF-PD) and the forestland (F-PD); (b) The correlation between the built-up area and the largest patch index of the non-forest vegetation (NF-LPI) and the forestland (F-LPI).

3.2 Detecting Urban Wet Landscapes at Fine Scales

To address questions raised in the landscape change detection at the metropolitan level, we used SPOT imagery to map wet-landscape change at fine scales in urban watersheds. According to the availability of quality images for the study area, two SPOT images were obtained for the study area: SPOT-5 of 2008 for use in identifying the current conditions of wetlands and other land cover types and SPOT-2 of 1992 for the past conditions of wetlands and other land cover types. The supervised maximum likelihood classification was used to classify the two images for the study area (Fig. 3 and Fig. 4).

The classification results reveal the same pattern identified from the land cover study described in Section 3.1: Both dry-landscape surface (the built-up areas) and wet-landscape surface (wetlands) gained in the study period (Table 2). This suggests that human built-up activities did not notably reduce urban wet-landscapes at a regional level while a slight increase of wetlands could be caused by other driving factors. The results (Table 2) also show that a significant loss of farmland / grass land was mainly caused by the increases of impervious surfaces and forestland in the study area.



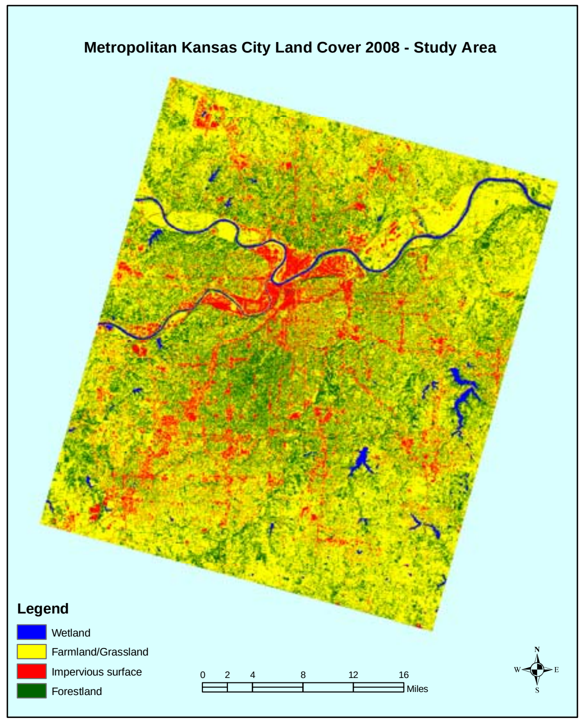


Fig. 3 (left): Classified image (1992) of the study area. **Fig. 4** (right): Classified image (2008) of the study area. The blue areas depict the distribution of wetlands while the red areas represent impervious surfaces. The yellow areas include mainly farmland and grass land. Forestland is shown in dark green.

Table 2. Land cover change of the study area between 1992 and 2008

	1992 land cover statistics		2008 land cover statistics			
Land cover type	Area (sq. km)	Cover %	Area (sq. km)	Cover %	Area Change	% Change
Wetlands	49.9	1.61	51.0	1.64	1.1.	0.03
Farmland/Grassland	2415.9	77.74	1996.4	64.16	-419.5	-13.58
Impervious surfaces	222.5	7.16	333.0	10.70	110.5	3.54
Forestland	419.3	13.49	730.1	23.47	310.8	9.98

3.3. Analyzing Factors that Might have Impacted Urban Wet-Landscapes

This effort is to identify major driving factors that might have affected urban wet landscapes at various scales. We examined three areas in relation to wet-landscape change:

(1) The impact of long-term precipitation trend

We obtained the precipitation data for our region from 1889 through 2008 from NOAA website (http://www.crh.noaa.gov/eax/localclimate/seasrank/monthlypcpn.php) (Fig. 5).

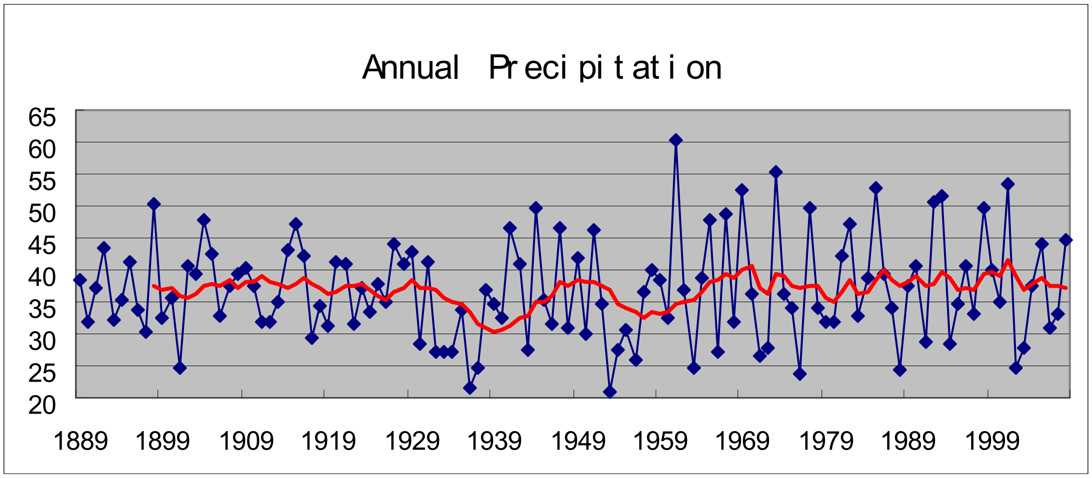


Fig. 5. The blue line shows annual precipitation variation from 1889 to 2008; the red line represents a 10-year moving average curve for precipitation in this period of time.

The data indicate that 2001 had the third largest precipitation in this period (the first was in 1961 and the second in 1974); the 1992-2001 period reached the maximum of the 10-year moving average curve. However, as shown in Fig. 5, the precipitation showed a slight declining trend toward 2008 – our second detection year of remote sensing. Thus, there was no clear evidence that the long-term precipitation trend had any correlation with the increase in urban wet-landscape coverage in the study area as detected by satellite remote sensing.

(2) The impact of short-term precipitation conditions

In this analysis, we sought to find out if there was any possible correlation between the detected wet-landscape areas and the short-term precipitation variation prior to two imaging dates of the SPOT imagery used in this study: Jan. 29 of 1992 and Oct. 8 of 2008. We obtained the daily precipitation data from a weather station (Bethany Station) near our study area. To assess the cumulative effect of precipitation, we summed up the precipitation data in different time periods we defined, up to 60 days, prior to the imaging dates (Table 3). The data indicate that the cumulative precipitation prior to Oct. 8, 2008 (“the current condition”) was significantly higher than that of Jan. 29, 1992 (“the historical condition”). This suggests that the short-term precipitation elevation might have swollen some water bodies in the study area, resulting in remotely sensed increase of wet-landscapes at both regional and local scales.

Table 3. *Cumulative precipitation prior to two imaging dates (data source: Bethany weather station, Missouri)*

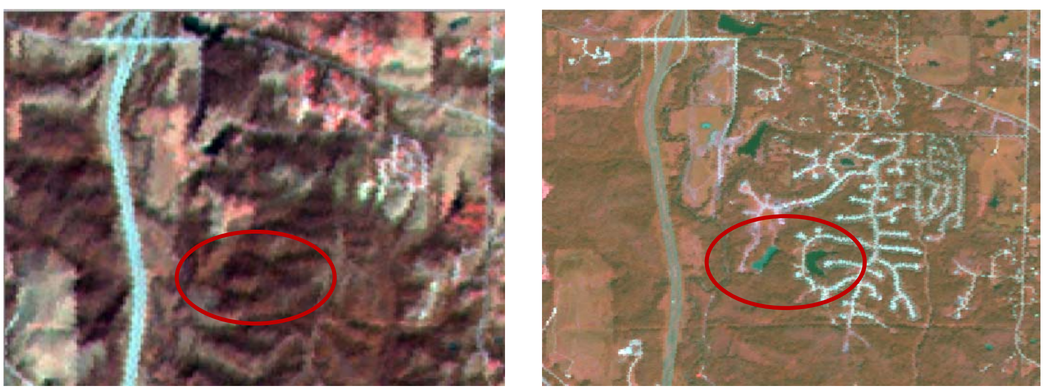
Date of SPOT imaging	**1 day sum**	**3 day sum**	**5 day sum**	**10 day sum**	**20 day sum**	**30 day sum**	**60 day sum**
Jan. 29, 1992	0	0	0	0	0.47	1.32	3.05
Oct. 8, 2008	0.42	0.42	0.42	0.54	1.24	6.87	10.42

(3) The impact of urban built-up activities

The impervious surface ("dry-landscapes") resulted from urban built-up activities. We found that these activities have affected wet-landscapes in two ways in the study area: reducing existing water bodies or adding new ones, both at fine scales (see examples in Figs. 6, 7 and 8).

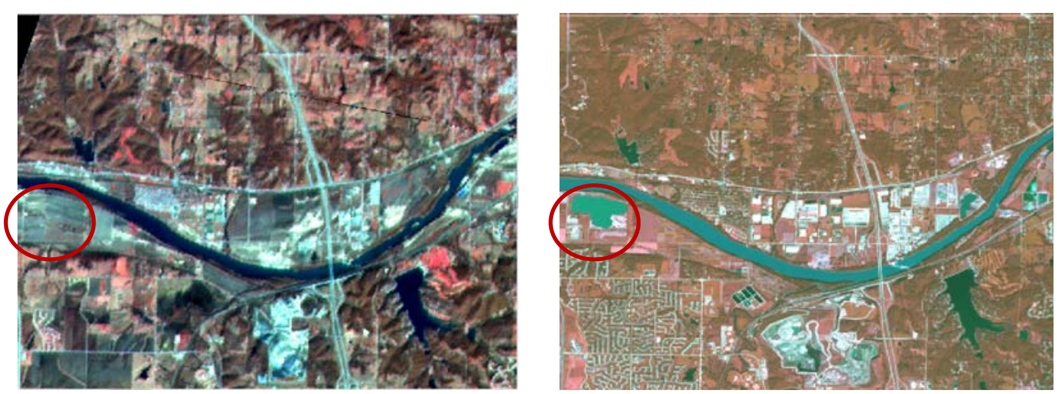
SPOT-2 image of 1992 SPOT-5 image of 2008

Fig. 6. Wet-landscape reduction: two circled water bodies that show on the 1992 image are non-existent in 2008



SPOT -2 image of 1992 SPOT -5 image of 2008

Fig. 7. Wet-landscape addition: two circled water bodies in 2008 image did not exist in 1992. The water bodies were created to service new residential areas



SPOT-2 image of 1992 SPOT-5 image of 2008

Fig. 8. Wet-landscape addition: a dam on the 2008 image has been constructed to supply water to the developing residential area.

4. CONCLUSION AND DISCUSSION

(1) The results of the quantitative urban land surface analysis suggest that, in the past decades, the study area experienced significant urban landscape alterations. Urban built-up area increase was mainly at the expense of non-vegetation lands, resulting in notable urban sprawling. Urban landscapes became more fragmented during the process of urban development. As such, the urban built-up area change serves as a good indicator of understanding human impacts on urban land covers. However, this variable is not effective to indicate the impact of precipitation on urban landscape transformation.

(2) Human built-up activities affected urban surface waters in two major ways: adding new water bodies or reducing existing ones. These impacts are more pronounced in the study area at fine scales.

(3) The study reveals that urban surface water (urban wetlands) increased its coverage in the study area at a regional level. The change of this wet-landscape was apparently correlated with the short term increase of precipitation in the region which occurred right before the imaging date of 2008 SPOT image. This suggests that urban wetlands can serve as a good indicator of understanding landscape change because they are sensitive to both precipitation conditions at a regional level and to human-activities at a fine scale.

(4) Detection of urban wet-landscapes and other land cover types using satellite remote sensing is still a technical challenge. For example, swamps and forested wet-landscapes can be confused with other land cover types such as grasslands or forestland, respectively. Both short-term precipitation at a regional level and human development at a fine scale must be taken into consideration when making impact assessment of urban landscapes based on remotely sensed data. Time of imaging is also crucial if the purpose is to detect seasonal wet-landscapes that only show in the rainy season.

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Dzingirai Murambadoro received the B.S. degree in Soil Sciences from the University of Zimbabwe, Harare, Zimbabwe, in 1994. He joined Soils Incorporated Inc., Harare, Zimbabwe as an assistant consultant from 1994 to 1997. He also received a M.S. degree in Geographic Information Systems (GIS) in 1999, again from the University of Zimbabwe. From 1999 to 2002, he joined the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) serving as a GIS Scientific Officer. From 2002 to 2005, he was with the Scientific and Industrial Research and Development Centre (SIRDC) – a national research institute – in Harare, Zimbabwe, as a research scientist in the Environment and Remote Sensing Institute (ERSI). Since 2000, he has been with University of Missouri-Kansas City studying for an Interdisciplinary PhD combining Geosciences and computer science. He is currently a Chancellor Scholar and a member of the ASPRS. His research interests include GIS, remote sensing and wetland research.