Identification of urbanization growth trend for Ahmedabad city in India using Remote Sensing and GIS

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ABSTRACT

With increasing urbanization and population pressure, the barren ground is altered from undisturbed soils to disturbed soils, which multiplies fast growth of impervious areas in cities. An impervious area is a modified surface that prevents water from infiltrating into the soil. Hydraulically connected impervious areas are denoted as effective impervious area (EIA) and hydraulically disconnected are denoted as non-effective impervious area (NEIA). The summation of above two impervious covers amounts to the total impervious area (TIA). Impervious surface data is important for urban planning and environmental and resources management. Therefore, remote sensing of impervious surfaces in the urban areas has recently attracted unprecedented attention. The estimation of TIA is comparatively simple as compared to the estimation of EIA, despite the fact that later is viewed as more proper for hydrologic studies. In this paper, emphasis was given on the estimation of impervious area (TIA) for the year 2000, 2010 and 2017 to scrutinize urbanization growth of Ahmedabad city in India using medium resolution satellite imageries by using geospatial techniques under the ArcGIS 10.1 platform. The more hydraulically relevant EIA is estimated using an empirical equation derived from the whole basin or sub-basin parameters from the estimated TIA. A graphical demonstration of the estimated EIA and TIA for different years is illustrated to analyze the rate of urban expansion.

Keywords: Urbanization, Impervious area, Total Impervious Area, Effective Impervious Area, Geospatial techniques.

1. INTRODUCTION

The word urbanization fuels the advancement of the human race in many aspects of life if correctly guided, systematized and framed but the negativity involved in an unframed urbanization is a threat to society as it may observe various unexpected and unavoidable calamities (Mohan *et al*. 2011). In spite of the fact that urbanization, which includes developed land covers or impenetrable surfaces inhabits only 2% of the worldwide land surface, many bits of confirmation demonstrates that human unsettling influence because of urbanization has altogether changed the regular scene. (Grubler,1994). With increasing urbanization and population pressure, the land surface is altered from unmoved soils along with regular vegetation to the digging of soils, supervised lands and construction materials which multiply faster growth of impervious surfaces in cities (Han and Burian, 2009). An impervious surface refers to an anthropogenically modified surface that prevents water from infiltrating into the soil such as pavements (roads, sidewalks, driveways and parking lots) that are covered by impenetrable materials such as asphalt, concrete, and rooftops (Chithra et al. 2013).These impervious surfaces without proper storm water control amend the water cycle which minimizes percolation frequencies and increases runoff peak discharges and capacity (Leopold, 1968). Hence, identification of rate of imperviousness is vital for speedily growing cities to have a command over urbanization (Sahoo and Sreeja, 2016). Satellite remote sensing images integrated with GIS have massively been applied for impervious surface identification and estimation due to low cost and suitability for large area mapping (Lu et al. 2013). It still remains a challenge to classify with medium or coarse spatial resolution imageries due to a large number of mixed pixels and the spectral confusions among different land-use/cover types.

Impervious surfaces may be divided into two categories: areas hydraulically connected to the downstream storm water collection system and areas draining to pervious surfaces. Hydraulically connected means water falling on the impervious surface will travel over an entirely impervious pathway until it reaches a storm water drainage system inlet. This is denoted as effective impervious area (EIA) and areas not connected hydraulically are denoted as non-effective impervious area (NEIA). The summation of above two impervious covers amounts to the total impervious area or TIA (Han and Burian, 2009). The estimation of TIA is quite simple (Lee and Heaney 2003) as compared to the estimation of EIA. But estimation of EIA is a better variable rather than TIA to handle the effects of urban land use land cover changes in certain years (Hatt et al. 2004). The appropriate calculation of EIA i.e. using direct method demands high-resolution satellite imageries and information regarding the drainage pipelines positioned in the city which may not be obtainable consistently. So to continue with our estimation process many researchers have adopted various indirect methods to determine EIA. The indirect methods (Heaney et al. 1977; Schueler 1994) for identification of effective impervious area consider changes in land activities, total impervious area (Alley and Veenhuis 1983; Sutherland 1995), inhabitant's growth etc.

2. RESEARCH AREA AND OBJECTIVE

Ahmedabad, the sixth largest city and former capital of Gujarat in India is ranked seventh in the list of growing urbanization. Ahmedabad lies at 23.03°N 72.58°E in western India at 53 m above sea level on the banks of the Sabarmati River, in north-central Gujarat covering an area of 464 km^2 (179 sq. mi). The city is divided by the Sabarmati into two physically distinct eastern and western regions which we can see in Figure 1. The eastern bank of the river houses the old city and the western bank houses the new city with highly developed architecture and growing urbanization. The urban agglomeration population has increased from 3.31 Million in 1991 to 4.5million in 2001 and according to the latest 2011 census the population of the city was more than 6.3 million and estimations predict a (constant) rise to 11 million inhabitants by 2035. It has emerged as a significant monetary and manufacturing hub in the country and is ranked second in the production of cotton. In 2010, the city was graded a rank of three by Forbes's in the context of rapidly developing metropolises within a span of time and in 2012, Times of India choose the city as India's finest city to live in. The city has also been selected to be urbanized as a smart city under Smart Cities Mission.

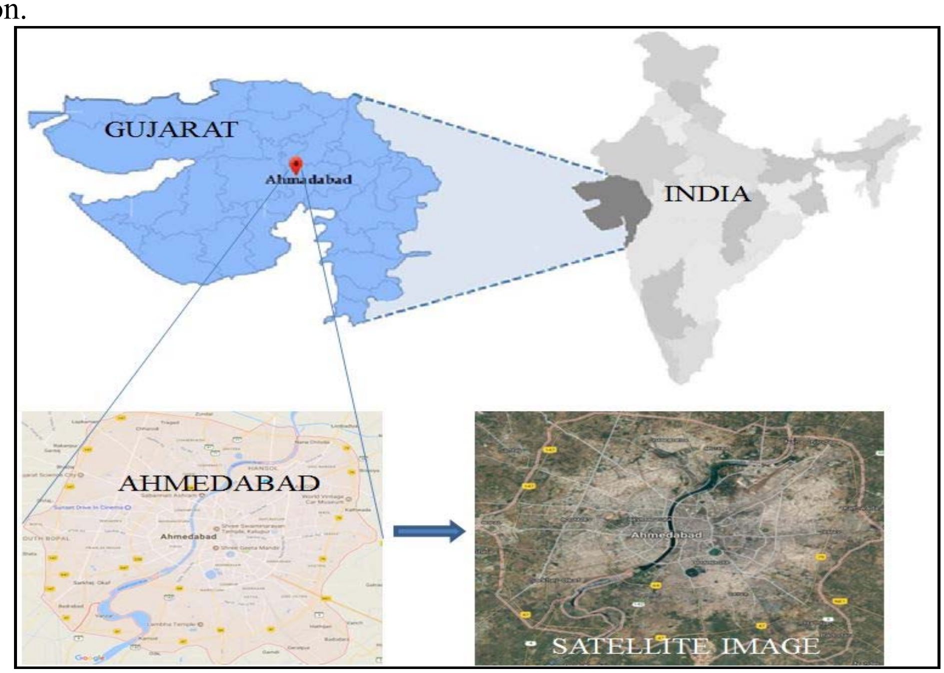

Figure 1: Pictorial representation of Ahmedabad city

2.1 Objective

This papers sole objective is to emphasize on the estimation of impervious area i.e. total impervious area (TIA) to indicate growth of urbanization for Ahmedabad city in India using medium resolution satellite imageries for different years i.e. 2000, 2010 and 2017 by using geospatial techniques. The more hydraulically relevant EIA is estimated using an empirical equation derived from the whole basin or sub-basin parameters from the estimated TIA. A graphical demonstration of the estimated EIA for different years is illustrated to analyze the rate of urban expansion.

3. METHODOLOGY

An amalgamation of remote sensing and GIS was applied for various satellite images available freely to estimate imperviousness in the present identification of urbanization growth trend of Ahmedabad city. In order to obtain the required imperviousness various Landsat images using different sensor and of the same spatial resolution were applied to the remote sensing platform. The GIS platform in which all these pre-processing, processing and post-processing of images as shown in Figure 2 were carried out using ArcGIS software developed by Esri (Environmental Systems Research Institute). The version of ArcGIS used was 10.1. Figure 2 below gives a pictorial clarification of the steps being followed during the processing of Landsat images to get our desired result.

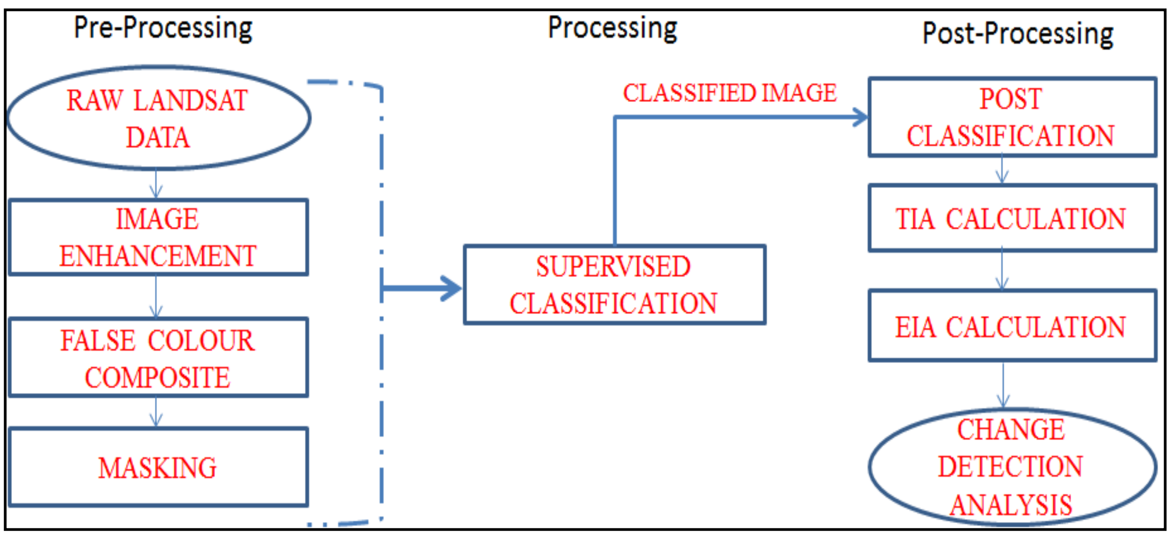

Figure 2: Flow chart demonstration of the methodology adopted for image analysis

The pre-processing work started with the collection of raw Landsat raster data i.e. medium resolution imageries of Ahmedabad city for the year 2000, 2010 and 2017 from various sources available freely in the electronic media. A detailed clarification of the raw data used in this change detection analysis is explained below in Table 1.

Table 1: Information of the Landsat imageries collected

SL No	Date of Imagery	Spatial Resolution (m)	Source of Data
1	22nd Oct 2000	30	Landsat ETM+, GLCF
2	04th Dec 2010	30	Landsat 5 (TM), USGS
3	05th Jan 2017	30	Landsat 8, USGS

In the above Table 1, the two abbreviations GLCF and USGS are elaborated as Global Land Cover Facility and United States Geological Survey respectively. This process of data collection was followed by the creation of False Color Composite (FCC) images of each year's Landsat data by assigning a band combination to identify red, green and blue from the total number of bands pre-assigned to each data. The Table 2 below gives a brief clarification regarding the correct band being chosen for each of the satellite images of different years for viewing their right FCC image.

Table 2: Details of band combination for FCC image

Sl No	Date of Imagery	Source of Data	Band Combination
1	22nd Oct 2000	Landsat ETM+	3,4,7
2	04th Dec 2010	Landsat 5 (TM)	3,4,2
3	05th Jan 2017	Landsat 8	3,4,1

The next step in pre-processing is the enhancement of the data i.e. adjusting the digital image which includes noise removal, sharpening or brightening of the image, radiometric and spatial enhancement etc. making it easier to identify key features from the FCC image for further analysis of the image. After this masking of the three different FCC images was done to extract the precise area of the shapefile regardless of the entire Landsat image to make things easy during classification. These masked FCC images work as a reference map for classification processing which is of two types unsupervised and supervised. But here we have gone with the supervised method of classification which means we have specified various pixels values or spectral signatures to each class i.e. done by selecting characteristic test spots of the known cover type called training samples. The computer algorithm then uses the spectral signatures from these training samples to classify the whole image. The algorithm used here is Maximum Likelihood classifier (MXL) as it proves to be one of the most efficient classification methodologies. The FCC images of three different years were classified individually under 5 different categories namely built-up, water, forest, barren land, and agriculture. But these five classes were again grouped into three groups: water, impervious area (built-up) and pervious area (forest, barren land, agriculture) to make further analysis uncomplicated. The classified image paves way for the post-processing part to begin which includes TIA and EIA calculation and the change detection analysis.

TIA broadly refers to the built-up/impervious area that obstructs the water to infiltrate into the soil and its calculation was done by computing the area covered by built-up/impervious class from the supervised classified image. This computed TIA included both EIA and NEIA but though EIA is an important parameter in determining urban runoff, hence computation of EIA from TIA is given priority. Direct determination of EIA is difficult and needs high-resolution imageries. Hence indirect methodology was adopted because of availability of coarse resolution imageries for estimating EIA. Several indirect approaches are proposed (Laenen 1980, 1983; Alley and Veenhuis 1983; Sutherland 1995; Sahoo and Sreeja 2016).

Sahoo and Sreeja (2016) used a more realistic semi-automated direct method to determine EIA by assimilating satellite imagery data, drainage map, and digital elevation model (DEM) for the city of Guwahati in India. EIA was estimated using two indirect methods i.e. Alley and Veenhuis (1983) and Sutherland (1995) equation and the results were compared. It was observed that Sutherland's equation results were nearby to the directly estimated EIA. A power relationship [Eq.1] was established to avoid overestimation of peak discharge for analyses like flood modeling. The values of TIA and EIA are in percentage of the area.

$$\text{EIA} = 0.0035 \times (\text{TIA})^{2.17} \quad (1)$$

4. RESULTS AND DISCUSSION

The raw Landsat image of Ahmedabad city was duly processed which included pre-processing, processing and post-processing along with appropriate methodologies for each step to get the desired output in change detection analysis. The urbanization growth trend of the city from (2000-2017) was analyzed by considering the imperviousness change within the city in these growing years. This imperviousness change analysis was again divided into two groups i.e. change in total impervious area (TIA) and effective impervious area (EIA) considering the later change to be more useful during runoff estimation within a city in its growing years. The initiation of output started with the extracted FCC image of the city for three different years as shown below in Figure 3. These FCC images helped in marking the training samples for identifying different classes during image classification.

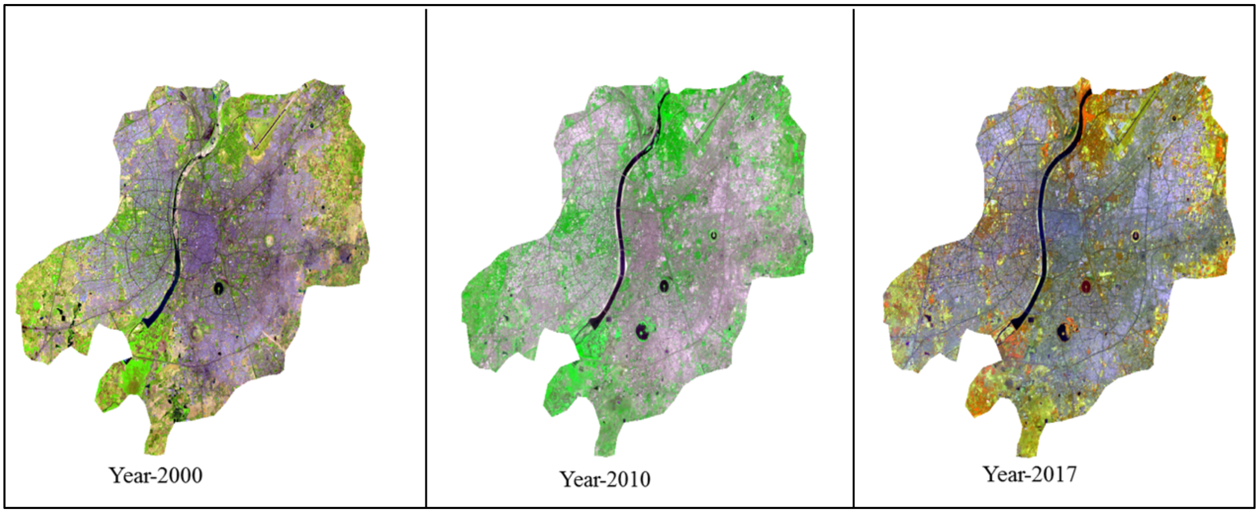

Figure 3: False Color Composite (FCC) of Ahmedabad city for different years

After masking of the FCC image, classification process begins with the assignment of training samples to each user defined class for clear identification. A total of 60 training samples were pointed in the FCC image of each year to classify it into three distinct classes namely water, impervious area and pervious area. Maximum likelihood classifier (MXL) algorithm was applied and the process of supervised classification was effective as shown in Figure 4.

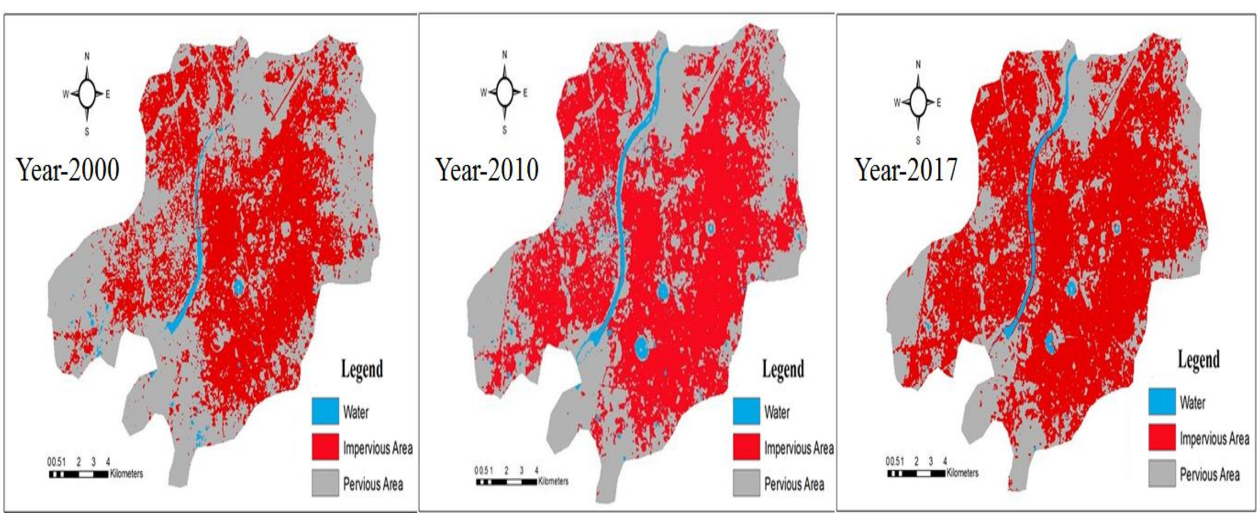

Figure 4: Classified Image of Ahmedabad city for the year 2000,2010 and 2017

The classes assigned to the classified image while processing the supervised classification are listed out along with their respective color in the classified image and the area acquired by each class for the year 2000, 2010 and 2017 in Table 3 below.

Table 3: Transformation recognition of different land covers

Sl No	Type of Class	Color in the classified image	Area (Sq.km)		
			2000	**2010**	**2017**
1	Water	Blue	3.3624	7.2252	4.872
2	Impervious Area	Red	126.23	140.15	151.97
3	Pervious Area	Gray	108.41	90.63	81.16
Total Area			238.00		

A graphical analysis of the change in land covers of Ahmedabad city during the year (2000-2017) is presented below with appropriate legends differentiating each defined class in Figure 5.

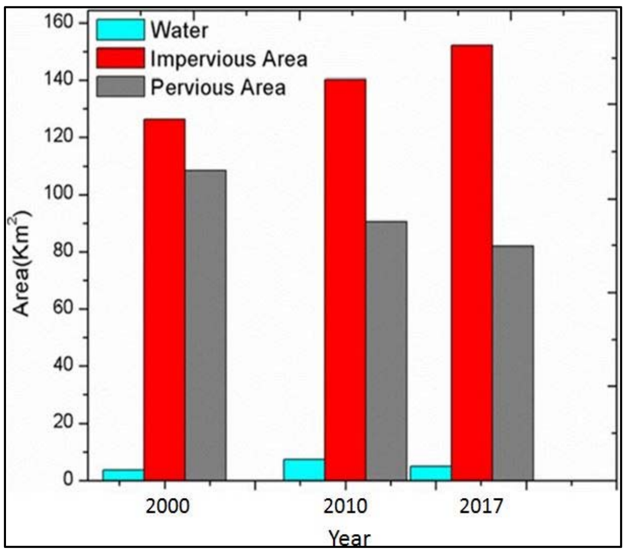

Figure 5: Change of different classes of Ahmedabad city

The determination of TIA was accomplished after the area of the impervious cover was calculated from the classified image of Ahmedabad city for each year. TIA was calculated in percentage for each year by dividing the impervious area of each year by the total area of the city and multiplying the answer with 100. Again EIA was calculated for each year by referring to the Eq.1 i.e. applying a respective value of each year TIA calculated to the empirical equation. In Table 4 below is listed out the calculated TIA and EIA values in percentage for the year 2000, 2010 and 2017 respectively.

Table 4: TIA and EIA of Ahmedabad city in percentage for different years

Sl No	Year	TIA (%)	EIA by Sahoo and Sreeja (Eq.1) (%)
1	2000	53.03	19.33
2	2010	58.88	24.26
3	2017	63.85	28.92

In the above figure, it can be clearly seen the growing impervious cover with respect to growing years which denotes a serious attention to be given in estimating the appropriate impervious cover to avoid any sort of issues like flooding etc. In the next figure is shown below i.e. Figure 6, a graphical comparison of the percentage of EIA and TIA of Ahmedabad city for the year 2000, 2010 and 2017 is presented.

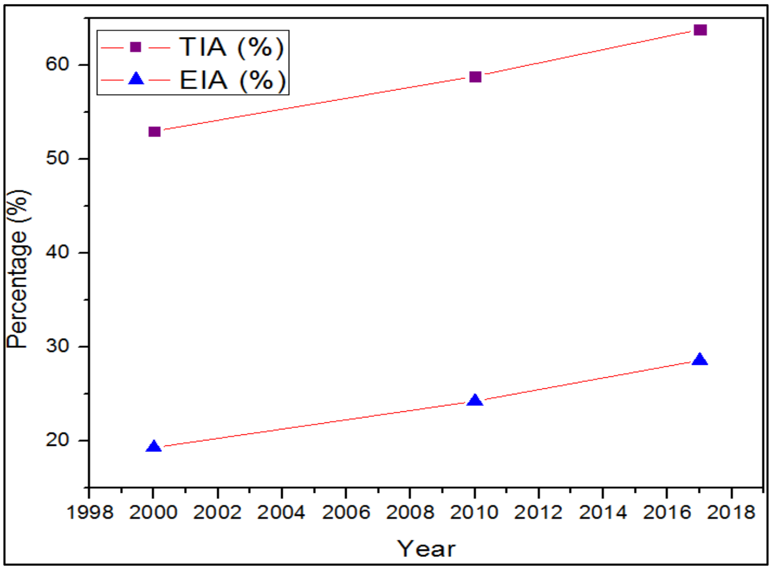

Figure 6: Comparison of EIA and TIA values in percentage

5. CONCLUSION

Changes in land use and land cover are pervasive, rapid, and can have significant impacts on people, economy, and the environment. Hence knowledge of the current state of the landscape and understanding current land cover and how it is being used, along with an accurate means of monitoring change over time, is vital to avoid any unwanted consequences. Remote sensing and GIS have played an important role in making things easy to analyze the urban growth change within a landscape and to monitor estimations like runoff, discharge etc. before hand to avoid flooding's etc. The city of Ahmedabad is experiencing a rapid urbanization in the last decade which is seen as one of the potential threats to sustainable development. In this paper, an attempt was initiated to identify such urbanization change during the period of 2000-2017 for the city of Ahmedabad. Though it was a challenging task to identify urban growth with coarse resolution imageries, the following points will better describe the results achieved.

a) The determination of TIA was relatively easy compared with the more hydraulically relevant EIA.

b) Supervised classification proved to be a good method for mapping impervious cover i.e. estimating total impervious area (TIA) with those data available.

c) EIA was estimated from TIA using an indirect methodology i.e. using an empirical relationship developed by Sahoo and Sreeja (2016).

d) The graphical analysis of TIA and EIA showed a linear growth in the increasing years which gave an indication of rapid mounting of urbanization and effective precautions to be considered in estimating runoff to avoid mishaps.

e) Fine resolution imagery is a must to analyze such change detection in terms of impervious area using direct methods and comparing it with some indirect methods to validate.

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REFERENCES

Alley, W. M., and Veenhuis, J. E. (1983). "Effective impervious area in urban runoff modeling." *J. Hydraul. Eng*., 109(2), 313–319.

Chitra, S V., Amarnath, A., Smitha, S V., Harindranathan Nair, M V. (2013). "Estimation of Effective Impervious Surface Area of Cochin using Satellite Images." *Research Journal of Recent Sciences.,* Vol. 2, 241-244.

Grubler, A. (1994). Technology. In changes in land use and land cover: A global perspective. pp. 287-328. Cambridge University Press, Cambridge.

Han, W., and Burian, S. J. (2009). "Determining effective impervious area for urban hydrologic modelling." *J. Hydrol. Eng*., 10.1061/ (ASCE) 1084-0699(2009)14:2(111), 111–120.

Hatt B.E., Fletcher T.D., Walsh C.J., Taylor S.L. (2004). "The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams." Environ. Manage. 34 (1), pp. 112-124.

Heaney, J. P., Huber, W. C., and Nix, S. (1977). "Storm water management model: Level I—Preliminary screening procedure." *EPA-600/2-76-275*, U.S. Environmental Protection Agency, Washington, DC.

Laenen, A. (1980). "Storm runoff as related to urbanization in the Portland, Oregon–Vancouver, Washington area." *USGS Water Resource Investigation Open File Rep*., Portland, OR, 80–689.

Laenen, A. (1983). "Storm runoff as related to urbanization based on data collected in Salem and Portland and generalized for the Willamette Valley, Oregon." *USGS Water Resource Investigation Open File Rep*., Portland, OR, 83–4143.

Lee, J. G., and Heaney, J. P. (2003). "Estimation of urban imperviousness and its impacts on storm water systems." *J. Water Resour. Plan. Manage*., 129(5), 419–426.

Leopold, L. B., (1968). Hydrology for Urban Land Use Planning: A Guidebook on the Hydrologic Effects of Urban Land Use. U.S. Geological Survey Circular, 554.

Lu, D., Li, G., Kuang, W., Moran, E. (2014) "Methods to extract impervious surface areas from satellite images". *Int. J. Digit. Earth* 2014, 7, 93–112.

Mohan, M., Pathan, S. K., Narendrareddy, K., Kandya, A., & Pandey, S. (2011). Dynamics of urbanization and its impact on land-use/land-cover: a case study of megacity Delhi. *Journal of Environmental Protection*., 2, 1274-1283.

Sahoo, S. N., and Sreeja, P. (2016). "Determination of Effective Impervious Area for an Urban Indian Catchment." *Journal of Hydrologic Engineering*., 05016004 (1-10).

Schueler, T. R. (1994). "The importance of imperviousness." Watershed Prot. Tech., 1(3), 100–111.

Sutherland, R. C. (1995). "Methodology for estimating the effective impervious area in urban watersheds." Watershed Prot. Tech., 2(1), 282–284.