Impervious Surface Detection and Mapping via Digital Remotely Sensed Techniques

Zuraini Basarudin, and Nor Aizam Adnan

***Abstract*—**Rapid development in urban area normally contribute impacts toward flood and others environmental hazardous. Floods occur when water unable to infiltrates into the ground or into the impervious surfaces such as built up area, paved land and motorway. Many hydrologists have claimed that urbanisation and land use changes accelerate floods to happen. One of the parameter uses in flood modelling known as impervious surface which can be derived from satellite imagery using digital image processing. Therefore, this paper intends to explore several indices of impervious surface index techniques known as Normalized Difference Water Index (NDWI), New Built up Index (NBI) and Fractional Impervious Surface Area (FIS) with capability to assist extracting built up area, urban changes monitoring and detection of the earth's surfaces. Kelantan, Malaysia has been chosen as study area due to urbanisation experience in the Kelantan River Catchment as well as this area normally affected by flooding during the North-East monsoon. These indices were then compared to the Enhancement Built up Index (ENBI) technique which is newly developed from this study. The impervious surface was determined based on Landsat TM satellite imagery acquired in 2004 for the Kelantan, Malaysia area. Additionally, widely practice classification using supervised (SCA) technique was produced in this study to determine the built up area.

***Keywords*—**Built up index, Digital image processing, Flood studies, Impervious surface indices, Landsat TM.

I. Introduction

IMPERVIOUS surfaces are defined as any surface or material prevent water infiltrate into soil and are primarily connected with transportation (streets, highways, parking lots and sidewalks) and building rooftops. Imperviousness directly affects the amount of runoff to streams and lakes and is related to non-point source pollution and water quality of surrounding lakes and streams. Impervious surfaces not only indicate urbanisation, but also major contributors to the environmental impacts of urbanisation. It will increase the frequency of natural disasters such as flooding by causing excessive runoff and hydrologic drought by eliminating natural groundwater recharge. Land use changes have been claims as one of the factor that contribute to the flood [1], [2], [3].

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Urban areas are conquered by built up lands with impervious surfaces, and therefore the conversion of the nature lands into these impervious built up lands may have significant impacts on the ecosystem, hydrologic system and local climate which can result in the unconstructive environment such as flood catastrophic. Providentially, satellite remote sensing technology offers substantial secure to helped mapping earth's surface. With the advancement of this technology, satellite observations able to help in extracting different land cover of the Earth's surface conditions that may change due various factors as portrayed in this study. The objectives of this study area to i) analyze different methods of impervious surface area (ISA) indices to extract urban built up land features from Landsat Thematic Mapper (TM) and ii) propose enhanced ISA detection method known as Enhanced Built up Index (ENBI)

II. Study Area

Kelantan River Basin is one of the major basins in Malaysia. It is located at the North Eastern part of Peninsular Malaysia at latitudes 4° 40' to 6° 12' North and longitude 101° 20' to102° 20' East. The Kelantan River Basin includes ten district totalling 15,022 km sq or about 5800 square miles. Kelantan is the most North-Eastern state of Peninsular Malaysia and it is bordered by Narathiwat Province of Thailand in the direction of the north, Terengganu to the south-east, Perak to the west, and Pahang to the south. Headed for the north-east of Kelantan is the South China Sea. The state is blooming with lush paddy fields, rustic fishing villages and casuarinas lined beaches. Kelantan is an agrarian economy and the state is driven by the production of rubber, rice, and tobacco. The population of Kelantan was about 1.6 million in 2013 which average annual population growth rate is 1.68 percentages [4]. The area includes a diversity of land cover classes. High and low density urban development characterizes the central portions of Kota Bharu and their suburbs, while several rural lands uses such as agricultural cropland, grassland, wetlands and forests, as well as small towns, are dispersed across the surrounding area. In the company of a 42.4 % level of urbanisation increment in Kelantan, the proportion of impervious area is undoubtedly as well has increasing. Therefore, Kelantan, Malaysia has been chosen as study area due to urbanisation experience in the Kelantan River Catchment as well as this area normally

affected by flooding during the North-East monsoon. The areas of Kelantan, Kota Bharu have been selected in this study due to its natural condition and the spatial complexity components in the urban area as well as consider frequently flood prone area.

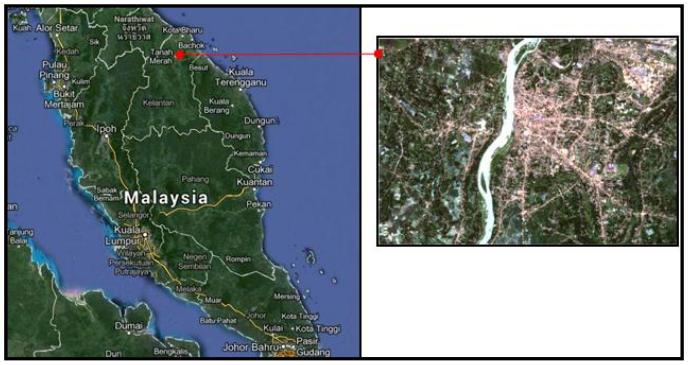

Fig. 1 Study Area at Kelantan, Malaysia

III. DATA AND METHOD

Impervious study has plays an important role in study related to environment analysis. In the company of enhancement technology in remote sensing and GIS, impervious surface can be detected and quantified due to their vast geographic coverage and temporal frequency of data collection, thus solved many environmental issue such as land cover for hydrological and environmental models. This study used four indices techniques and image classification to extract built up area. The guideline to quantify degree of ISA (in %) as shown in Table 1. The satellite image Landsat TM acquired in 2004 with resolution 30 meter used for this study. As described earlier this study tries to analysis different available ISA indices as provided in Equation (1) to (7) below.

A. ISA Indices and image classification

There few indices were used in this study. The NDBI index was proposed by Zha et al.[5] is defined as Eq. (1).

$$NDBI = \frac{SWIR-NIR}{SWIR+NIR} \quad \text{-------} \quad (1)$$

While Ridd [6] and Owen et al.[7] showed that the relation between the fractional vegetation cover (FVC) and fractional impervious surface area (FIS) for developed areas as:

$$FIS = 1 - FVC \quad \text{----------} \quad (2)$$

Which,

$$NDVI_s = \frac{NDVI - NDVI_{low}}{NDVI_{high} - NDVI_{low}} \quad \text{-------} \quad (3)$$

Calson and Ripley [8]

$$FVC \approx (NDVI_s)^2 \quad \text{------} \quad (4)$$

Where FVC ranges is between 0 and 1.

TABLE I
DEFINITION OF URBAN LAND USE TYPES

Urban land-use type	Code	Definition
Low-intensity residential lands	LIRL	Impervious surface is very low, usually less than 30%, population density is less than 500person/km^2
Medium-intensity residential lands	MIRL	Impervious surface is usually greater than 20%, but often less than 50%, population density is beween 500 and 1500persons/km^2
High-intensity residential lands	HIRL	Impervious surface is usually greater than 40%, population density is between 1500 and 3000persons/km^2
Very-intensity residential lands	VIRL	Impervious surface is usually greater than 3000person/km^2
Commersial, industrial, and transportation lands	CITL	Impervious surface is usually greater than 60%, population density is very low, usually less than 10person/km^2
Non-urban Lands	NURL	Vegetated areas and agriculture lands
Water	WAT	Water bodies

Source from Dengsheng Lu and Qihao Weng [11]

New Built up Index (NBI) by Jieli et al [9] is derived as (5)

$$NBI = \frac{TM3-TM5}{TM4} \quad \text{----------} \quad (5)$$

McFeeters [10] proposed the Normalized Difference Water Index (NDWI) as:

$$NDWI = \frac{Green-NIR}{Green+NIR} \quad \text{----------} \quad (6)$$

An enhancement to ISA built up index was introduced and created by subtracting FVC from NDWI indices as follow:

$$ENBI = NDWI - FVC \quad \text{-------} \quad (7)$$

Image classification is the generally and widely used method in extraction of impervious surface[11],[12] however the land use classes derived are often not satisfactory because of the limitation of spatial resolution in remote sensed imagery and the heterogeneity of urban landscapes. A range of impervious surfaces may be mixed with other land cover types, such as forests, soils, and pastures. Furthermore, the difficulty in selecting training areas might also inferior the accuracy of image classification. In this paper, the classification of impervious surface for this study was performed using ERDAS Imagine software utilizing the Maximum Likelihood classification method.

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TABLE II
CLASSIFICATION RANGE

CLASS/INDICES	FIS	NDWI	NBI (DN: 0-255)	ENBI
WATER BODIES	> 0.9	>0.5	0-25	-1.5 - 0.55
BUILT UP AREA (ISA)	0.7-0.9	-0.5- -0.4	70-255	-0.7 - -1.5
MIXED AGRICULTURE	0.4-0.69	-0.4- -0.25	0-25	-1.3 - -0.9
BARREN LAND	0.25-0.4	-0.25- 0.015	44-70	-0.9 - -0.7
FOREST	0.1< FIS<0.25	0.015- 0.15	0-25	>-1.3

The general methodology adopted in this study shown in Figure 2. The satellite imagery Landsat TM acquired in 2004 was used in extracting impervious surface (ISA).

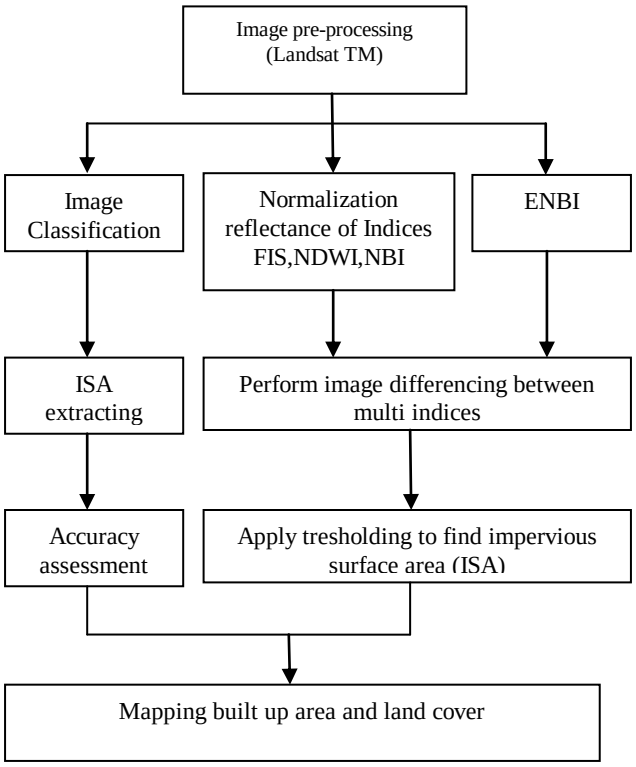

Fig. 2 Research Methodology

IV. RESULTS AND DISCUSSION

The Maximum likelihood classification method was utilized to classify the study area into five land use types: built up, water, forest, mix agriculture and barren land. The user's accuracy of impervious area classification is 58.88% compared to producer's accuracy of 98.44%. The overall accuracy is 61.54% for five classes. However, none of classification method is perfect because it is depend on the regional land cover surface.

Table II shows different values of each ISA indices used in this study. The NDWI and ENBI have produced negative values for built up area, while FIS give the positive value. The NBI come out with DN value 70-255 as consider built up area. All values are focus on high dense built up only for respective indices.

Various researcher have study the impervious surface impact to the hydrology and environment. The study by Zhou et al. [13] found that the percentage of impervious surface area is closely related to the hydrologic pattern in Rhode Island. Similarly, Hejazi et al.[2] found that urbanisation give more impact on the peaks floods than precipitation, with average contribution of urbanization was 34% higher. As well as study by Gallo et al. [14] found that urbanisation does significantly increase runoff frequency and duration. The effect of land cover on the catchment has increased impervious channelization increases the probability of runoff from small rainfall events. Accordingly, study by Basarudin et al.[15], use curve number (CN) refer to land use classification in assessing impact of land use on the hydrological impact at Kelantan River Catchment. The results show by retain the land use, rainfall change has a significant impact to determine the peak discharge and runoff depth for the study area. On the whole, this is proven that impervious surface area plays an important role in flood and environmental studies.

The classification result of the FIS, NDWI, NBI and ENBI method is shown in Fig. 3 and Fig. 4. Clearly the performance of respective method is good, primarily in terms of delineating built up area from surrounding features in the heterogeneity environment.

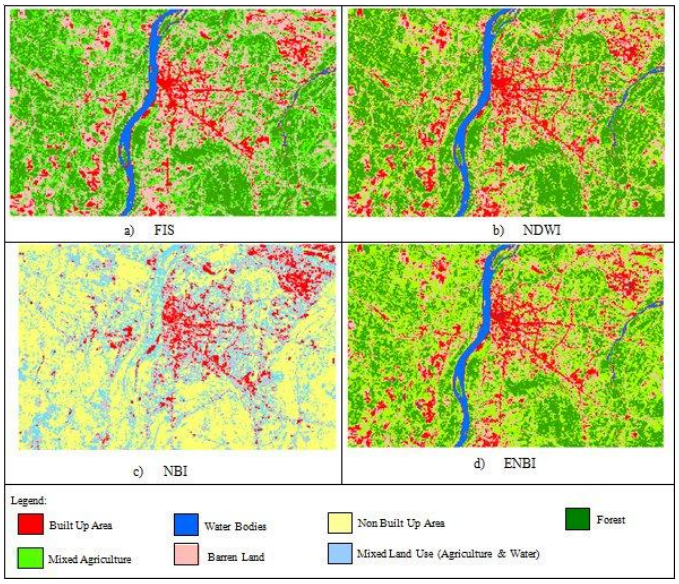

Fig. 3 Mapping of land use using indices techniques

The ISA indices results (Fig. 3 and Fig. 4), it were observed that the ENBI indices algorithm produces better classification results of impervious surface area (ISA) than NDWI, FIS and NBI indices techniques. Comparing ENBI with NBI, ENBI does expressly differentiate the ISA and none ISA better (Table 3). An enhancement built up (ENBI) is promoted as an effective and better algorithm to identify built up regions, compared with the NBI approach. The NBI method, which makes use only spectral patterns, was unable to differentiate water from mixed agriculture because of their similarity in spectral response.

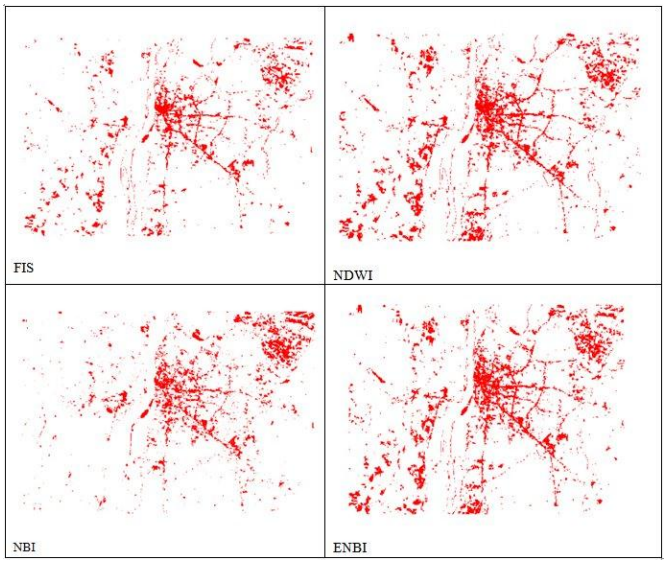

Fig. 4 Impervious surface extraction by difference indices

The NBI algorithm has confusing in identified water and non water and it has categorized under the same group of non ISA (ie. mixed agriculture). The others three algorithm (i.e FIS, NDWI, ENBI) were able to differentiate water bodies and others classes clearly. As well as, NDWI technique also an effective algorithm to identify built up area compared with FIS and NBI approaches.

V. Concluding Remarks

The ISA indices as used in this study proven able to extract built up areas and able to discriminate features and considerably reduces confusion among spectrally similar classes. Furthermore, the ISA indices used in this study are simple in application and less time-consuming compared to the other method such as the maximum likelihood classification. Additionally, these indices can be used to develop images that can serves as a reference for other classification techniques in order to assess land use map accuracy. The enhanced ISA index known as ENBI algorithm is capable to determine the impervious area at the heterogeneous area such as at Kota Bharu Kelantan. Potentially, the ENBI technique proposed in this study indicate better result for the extraction of built up area which might differentiate the pervious and impervious surfaces from the Landsat TM imagery. The results show that the impervious area obtained from the ENBI has acquire reasonable accuracy for built up area detection compared to the other five techniques (i.e. NDWI, NBI, FIS and SCA). Therefore the technique proposed in this study may be suitable to be use as an early detection of flooding impact and inundation in floodplain area due to changes in land use.

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