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Land use and land cover change analysis 1990-2002 in Binh Thuan Province, south central Vietnam

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Abstract - *Describing the nature and extent of land resources and changes over time has become increasingly important, especially in developing countries. In this study, two Landsat satellite image scenes were examined to identify land use and land cover changes in Binh Thuan province (Vietnam) between 1990 and 2002. Classification accuracies were based upon ground truth data obtained by global positioning system and field collection. A post-classification comparison analysis was used to identify areas that have experienced conversions in land use and land cover. Comparisons of the land cover maps reveal that a steady growth in population has caused extensive changes of land cover throughout the area. The maps also indicate that the loss of woody land (forest) and the extension of wetlands (irrigate area), combined with built-up encroachment, remains one of the most serious environmental problems facing the Binh Thuan Province today. The post-classification change detection analysis showed that critical habitats accounted for nearly 38.5% of the total intensive study area between 1990 and 2002 while 61.5% remained stable. Results also showed over the 12-year span, approximately 1151.2 km² (115.120 ha) forest were converted respectively to brush, irrigated area (wetlands), cropland and built-up. This is an overall average decrease of approximately 9594 hectares of forested area per year. Throughout the study area, districts most affected by forest conversion to another land cover are: Bac Bihn (2798 ha/year), Than Linh (2717 ha/year), Ham Thuan Nam (1601 ha/year) and Ham Thuan Bac (1524 ha/year). Based on the identified causes of these changes, we made policy recommendations for better management of land use and land cover.*

Keywords: Land cover, Change detection, Landsat, Binh Thuan, Vietnam

I. INTRODUCTION

The research on the land use/cover change is one of the frontiers and the hot spots in the global change research. The urban growths, deforestation, extension of the cultivated lands are the main talks in the current scenario of rapid changes in the climate. The change of the land cover of a specific area over a time period can provide us information on how sustainable the land has been used. While standard ground survey methods for undertaking such measurements are imperfect or expensive it has been demonstrated that satellite-based and airborne remote sensing (RS) systems offer a considerable potential. This capacity for quantitative land-surface monitoring over large areas makes RS well-suited for a very wide range of disciplines, including land-use planning and providing spatial information needed for local or regional-scale analyses of the relationships between climate change, land degradation and desertification processes [1]. Therefore, studying the change detection by remotely sensed data's of different date's remains a challenge because of factors such as the complexity of the landscape in a study area selected remotely sensed data. Change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times [2]. This technical issue is useful in many applications related to land use and land cover (LULC) changes, such as shifting cultivation and landscape changes [3], land degradation and desertification ([4]; [5]), urban sprawl [6], deforestation ([7]; [8]), landscape and habitat fragmentation and other cumulative changes [9]. Continual, historical, and precise information about the LULC changes of the Earth's surface is extremely important for any kind of sustainable development program, in which LULC serves as one of the major input criteria. Satellite remote sensing is the most common data source for detection, quantification, and mapping of LULC patterns and changes because of its repetitive data acquisition, digital format suitable for computer processing, and accurate georeferencing procedures ([10]; [11]). The successful use of satellite remote sensing for LULC change detection depends upon an adequate understanding of landscape features, imaging systems, and methodology employed in relation to the aim of analysis [12]. Many change detection techniques have been developed and used for monitoring changes in LULC from remotely sensed data, such as post-classification comparison (PCC), image differencing, principle components analysis, and vegetation index differencing [13]. The PCC method, which is recognized as the most accurate change detection technique, detects land cover changes by comparing independently produced classifications of images from different dates. Using the PCC method thus minimizes the problems associated with multi-temporal images recorded under different atmospheric and environmental conditions. Data from different dates are separately classified, and hence, reflectance data from multi-dates do not require adjustment for direct comparability ([14]; [15]). There are currently numerous satellite programs in operation. For change detection studies, the Landsat program is unique because it provides an historical and continuous record of imagery. Landsat images can be processed to represent land cover over large areas and over long time spans, which is unique and absolutely indispensable for monitoring, mapping, and management of LULC [16].

This paper aims to investigate spatial and temporal land cover changes in Binh Thuan province in the southern central Vietnam and understand the possible causes of the changes. To do this, we applied land classification schemes to classify the land cover types using Landsat data focus on six districts included in Binh Thuan province. Based on the previously developed methodology such as maximum-likelihood classification and change detection techniques, we assessed the accuracy of the land classification techniques by comparison with supervised classification based on numerous ground truth data. Land cover changes between 1990 and 2002 were quantitatively presented with the results of accuracy assessments. We also suggested recommendations regarding towards better management of LULC.

II. *DATA AND METHODS*

A. *Study area*

Locate between 107°24’ – 108°50’E and 10°33’–11°33’N (Fig. 1), Binh Thuan is a sea coast province of south of central Vietnam, having north-east border with Ninh Thuan province, north-west border with Lam Dong province; west border with Dong Nai province; south-west border with Ba Ria - Vung Tau province; east and south-east border with the South China Sea. Total land area is 7830.4 km² [17] and the province has 8 districts, 1 city and 125 towns, communes.

This region is the driest and hottest region of Vietnam. The area faces the Pacific Ocean to the east with a coastline of about 192 km and is characterized by a combination of tropical monsoon and dry and windy weather. The Binh Thuan Province can be divided into 4 main landscapes: Sand dunes along the coast - alluvial plains - hilly areas – and the Truong Son mountain range. The mean annual temperature is 27°C, with average minimum 20.8°C in the coldest months (December, January), and an average maximum of 32.3°C in the hottest months (May and June). Rainfall in this area is limited and irregular. Annual average precipitation is 1024 mm, while evaporation in some years is equivalent to precipitation. At some locations annual rainfall can be as low as 550 mm. The dry season is from November to April, with 60 days of January and February having almost no rain. The rainy season is from May to October with heavy rains concentrated in a short periods with up to 200 mm/day. The total population of the province in 2004 is around 1.140.429 so urban conditions have improved in recent years through the extension of water supply networks and road upgrading.

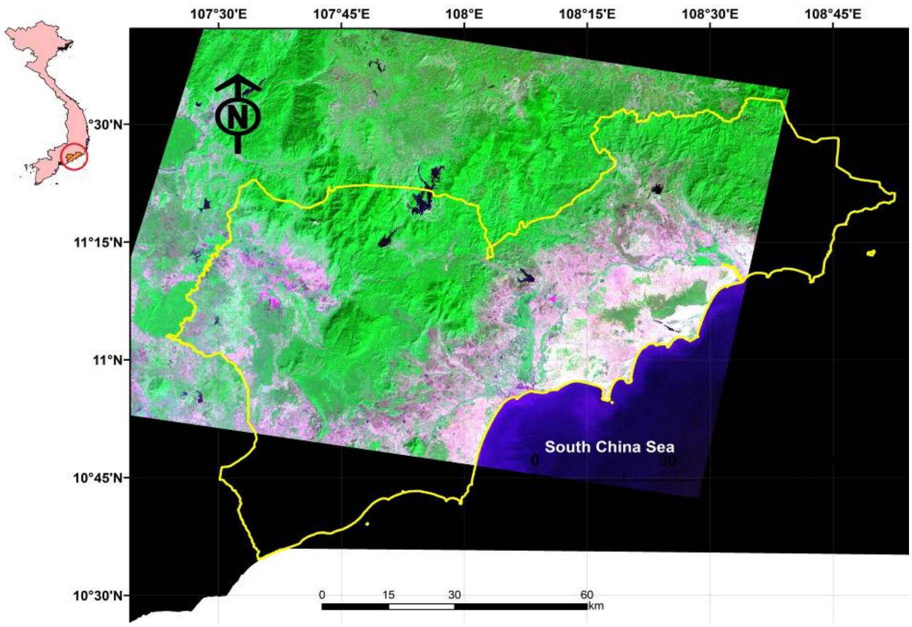

Fig. 1: Location of Binh Thuan province and area covered by Landsat ETM+ image subset (05.01.2002)
False color (RGB: TM3, TM 4, TM 2)

B. *Data acquisition and processing*

A pair of cloud-free Landsat images were selected to classify the study area: December 30, 1990 (Landsat-5 TM) and January 05, 2002 (Landsat-7 ETM+). These time series of Landsat images are freely available from the Landsat archive from the United States Geological Survey (USGS) [18]. All visible and infrared bands (except for the thermal infrared band) were included in the analysis. Only the intersected area (province boundary and image subset) has been taken into account for spatial statistics. Six of the nine districts of Binh Thuan province were contained within Landsat path 124, rows 52. All images were rectified to UTM zone 48N, GRS 1984, using at least 35 well distributed ground control points. The root mean square errors were less than 0.25 pixel (7.125 m) for each of the two images.

We used the Environment for Visual Imaging software (ENVI version 4.4) [19] developed by Research System Incorporated (RSI) for digital image processing of the subsets of chosen Landsat images described above. Image processing included images calibration to reflectance, enhancement, rectification, and sub-setting. The accuracy of the classification was determined based upon ground truth region of interest (ROI). Each class included a different number of ROI's, depending upon the albedo and contrast of class types. Training samples were selected for each of the predetermined LULC types by delimiting polygons around representative sites. Using the pixels enclosed by these polygons, we derived spectral signatures for the respective land cover types recorded by the satellite images. A spectral signature is considered to be satisfactory when 'confusion among the land covers to be mapped is minimal [20]. Once the spectral signature was deemed satisfactory, we entered it into the classification process. Ground truth ROI's were divided into two groups. The first group is for classification procedure and the second group is for accuracy assessment. Two LULC maps were produced (for 1990 and 2002). Our classification scheme, with seven classes (Table 1), was based on the land cover and land use classification system developed [21] for interpretation of remote sensor data at various scales and resolutions.

TABLE 1: LAND COVER CLASSIFICATION SCHEME

Land cover class	Acronym	Description
Built-up	BUP	Urban or rural build-up - industrial – transportation – cities – towns -villages
Forest-Plantation	FPO	Natural forest - reforested land - mixed forest – orchards - groves
Dunes and sandbank	DSB	Dune roving - sandbank
Crop land	CLD	All arable land (not limited to land under crops) – rain-fed crop fields and bare fields
Highland and Bush	HIB	High lands or hills with vegetation – wild lands with spare vegetation – unused land
Water bodies	WAT	Permanent open water – lakes – reservoirs – streams - bays and estuaries
Lowland	WET	Irrigated cropland - paddy field - water ponds - flooded lands.

A supervised training approach was used with maximum likelihood classification [22]. Since several research have produce different land classes ([23], [24], [25]) than those of our Landsat classification, data from both sources were aggregated into seven categories. Class histograms were checked for normality and small classes were deleted. Post-classification refinements were applied to reduce classification errors caused by the similarities in spectral responses of certain classes such as bare fields and urban and some crop fields and wetlands. An independent sample of an average of 40 polygons, with up to 100 pixels for each selected polygon, was randomly selected from each classification to assess classification accuracies. Error matrices as cross-tabulations of the mapped class vs. the reference class were used to assess classification accuracy [26]. Overall accuracy, user's and producer's accuracies, and the Kappa statistic were then derived from the error matrices. The Kappa statistic incorporates the off diagonal elements of the error matrices (i.e., classification errors) and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance. Finally, a 3x3 majority filter was applied to each classification to recode isolated pixels classified differently than the majority class of the window.

C. *Change detection*

Following the classification of imagery from the individual years, a post-classification comparison change detection algorithm was used to determine changes in land cover in 1990–2002 intervals. This is the most common approach to change detection [27] and has been successfully used to monitor land use changes in previous studies ([28]; [13]; [14]; [15]). Post-classification comparison (PCC) was employed to detect the differences between each pair of LULC maps (1990 and 2002). The PCC approach provides ''from–to'' change information and the kind of landscape transformations that have occurred can be easily calculated and mapped. A change detection map with 49 combinations of ''from–to'' change information was derived for each of the two seven-class maps and then, a change map was compiled to display the specific nature of the changes between the classified images.

III. Results

Results presented in the following sections are restricted to the area of Binh Thuan province for which the chosen Landsat scenes intersected with provincial boundaries. This overlapped area covers 6070 km^2 representing 78.9% of the total area of the province.

A. *Classification maps accuracies and statistics*

Before using the classification results for change detection, we assessed their validity by testing the results against ground truth data. Error matrices were used to assess classification accuracy and results are summarized for the two years in Table 2.

The overall accuracies for 1990 and 2002 were, respectively, 98.05% and 91.41%, with Kappa statistics of 96.61% and 87.98%. User's and producer's accuracies of individual classes were consistently high, ranging from 99% to 76%. FPO, WAT and HIB classes were all characterized by the highest classification accuracy. This is because the integration of the results of visual interpretation and supervised classification, which allowed us to correct the misclassified pixels.

TABLE 2: SUMMARY OF LANDSAT SUBSET CLASSIFICATION ACCURACIES (%) FOR 1990 AND 2002

Land cover class	Acronym	1990		2002	
		Producer's	User's	Producer's	User's
Built-up	BUP	97.59	87.22	80.04	76.66
Forest-Plantation	FPO	99.47	77.58	98.48	85.75
Dunes - sandbank	DSB	98.13	99.58	88.66	99.63
Crop land	CLD	94.82	98.05	95.85	94.39
Highland and Bush	HIB	98.80	99.95	91.25	99.96
Water bodies	WAT	99.18	99.98	99.96	98.17
Lowland	WET	97.89	78.58	95.26	86.51
Overall accuracy (%)		98.05		91.41	
Kappa statistic(%)		96.61		87.98	

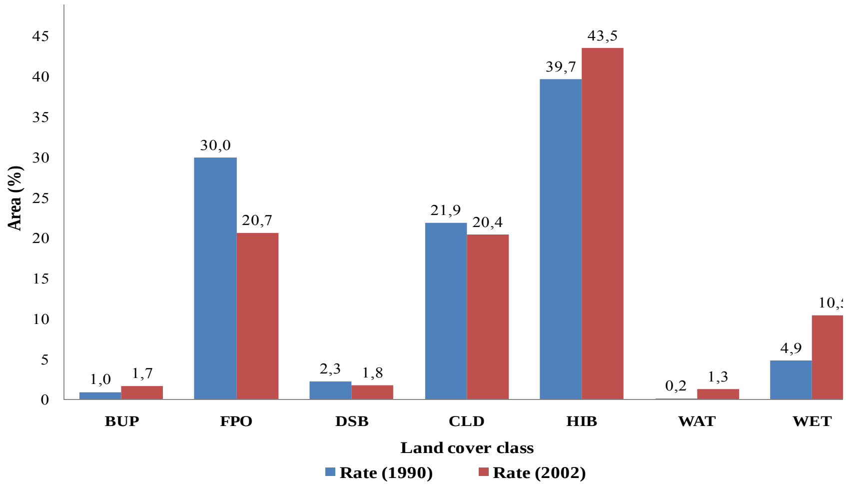

Fig. 2: Area percentage of each land cover class resulting from the classified images (6070 km^2) for 1990 and 2002.

The data presented in Fig. 2 and Table 3 represent respectively the rate and the total area of each LULC class for 1990 and 2002. In 1990, HIB was the largest class, representing 2407 km^2 of the total LULC categories assigned, occupying 39.7% of the study area. In 2002, this class amount had increased significantly, resulting chiefly in the reduction of forest and plantation class (from 30% in 1990 to 20.7% in 2002). With the exception of the Lowland class (WET: 4.9%) and the dune roving (DSB: 2.3%) in 1990, built-up (BUP) and free-water bodies classes (WAT) accounted for the lowest percentages of the total LULC categories in all study years.

The major changes during 1990-2002 periods were found in FPO class (natural forests including planted forest), WET class (irrigated land, paddy fields) and HIB class (vegetation re-growth, shrubs, hill's vegetation). The areas of water bodies and built-up (urban or rural settlements) also increased significantly. Thus, from 1990 to 2002, BUP, HIB, WAT and WET area increased respectively 0.7% (44.3 km^2), 3.8% (233.6 km^2), 1.1% (67.1 km^2) and 5.6% (341.2 km^2) while FPO, DSB and CLD decreased 9.3% (562 km^2), 0.5% (31.5 km^2) and 1.5% (92.2 km^2). Although the extent of wetlands may change from year to year due to varying precipitation and temperature, the variation in wetland area is also likely due to classification errors. However, the fluctuations in Lowlands classification errors are believed to be related to varying sol humidity levels given the high classification (producer's accuracy about to 97.89% in 1990). The spatial distribution of the assigned categories for each year is shown in Fig. 3

TABLE 3: AREA OF EACH LAND COVER CLASS CLASS RESULTING FROM THE CLASSIFIED IMAGES.

Land cover class	Acronym	1990		2002	
		Area (km²)	Rate (%)	Area (km²)	Rate (%)
Built-up	BUP	60.8	1.0	105.1	1.7
Forest-Plantation	FPO	1818.1	30.0	1255.4	20.7
Dunes - sandbank	DSB	141.9	2.3	110.4	1.8
Crop land	CLD	1332.2	21.9	1240.0	20.4
Highland and Bush	HIB	2407.0	39.7	2640.6	43.5
Water bodies	WAT	13.4	0.2	80.5	1.3
Lowland	WET	296.6	4.9	637.8	10.5
Total (km²)		6070	100	6076	100

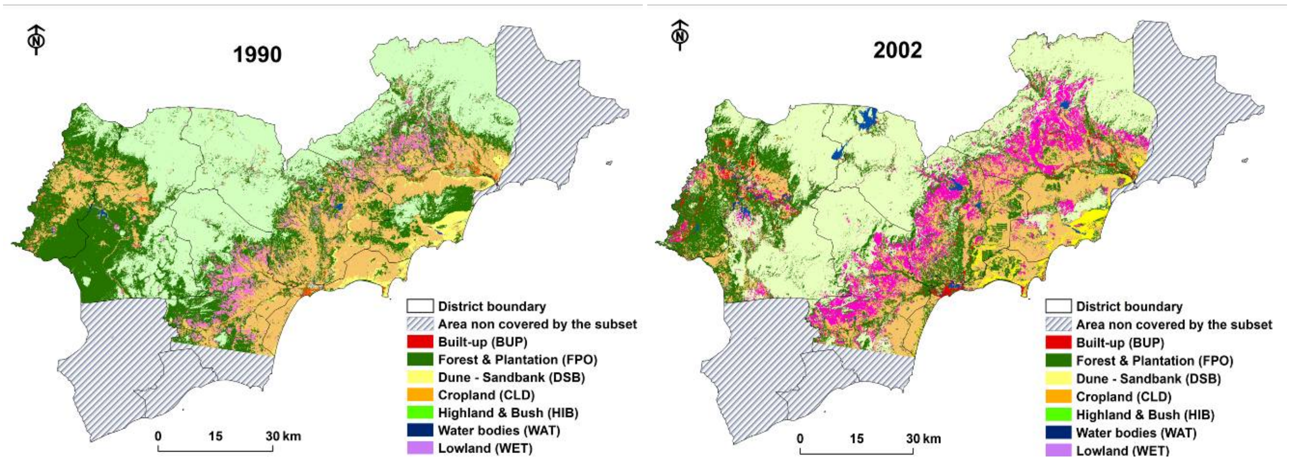

Fig. 3: Land use and land cover maps (1990 and 2002) resulting from the integration of supervised classification and visual interpretation

B. Analysis of change patterns

By constructing a change detection map, the advantages of satellite remote sensing in spatially disaggregating the change statistics can be more fully appreciated. Our results showed over the 12-year span, 3735.5 km² (61.5% of the studied area) were unchanged while changes occurred elsewhere (38.5%), Table 4. These unchanged areas were mainly composed by HIB (34%), CLD (12.7%) FPO (11%) and WET class (2.2%). In order to examine more specifically areas where changes affected more than 5 km², a table showing combinations of ‘‘*from–to*’’ change has been gathered (Table 5). The selected results represented 99% of the major changes that occurred during the studied period and the spatial distribution of the resulting conversion classes is shown in Fig. 4.

TABLE 4: AREA AND PERCENTAGE OF CHANGE IN EACH LULC CLASS AND ANNUAL RATE OF CHANGE BETWEEN THE DIFFERENT DATES

LULC class	Districts included						Total change (km²)	Rate (1990-2002)
	Bac Binh	Duc Linh	Ham Thuan Bac	Ham Thuan Nam	Phan Thiet	Tanh Linh		
BUP	17.7	29.1	13.5	6.3	6.2	17.0	89.9	1.5
FPO	149.2	78.1	162.8	77.3	37.6	83.6	588.6	9.7
DSB	14.2	0.1	9.4	0.5	10.5	0.3	35.1	0.6
CLD	187.7	36.6	92.7	68.9	18.4	65.4	469.6	7.7
HIB	108.8	54.6	64.0	94.8	1.2	252.5	575.9	9.5
WAT	10.9	7.9	27.0	2.2	3.6	18.0	69.6	1.1
WET	204.2	16.2	130.3	118.5	3.4	33.1	505.7	8.3
Changed area (km²)	692.7	222.8	499.7	368.5	80.8	469.9	2334.4	38.5
Unchanged area (km²)	1169,0	323,3	845,2	536,1	130,9	731,0	3735,5	61,5
District area (km²)	1861.7	546.1	1344.9	904.6	211.7	1200.9		100

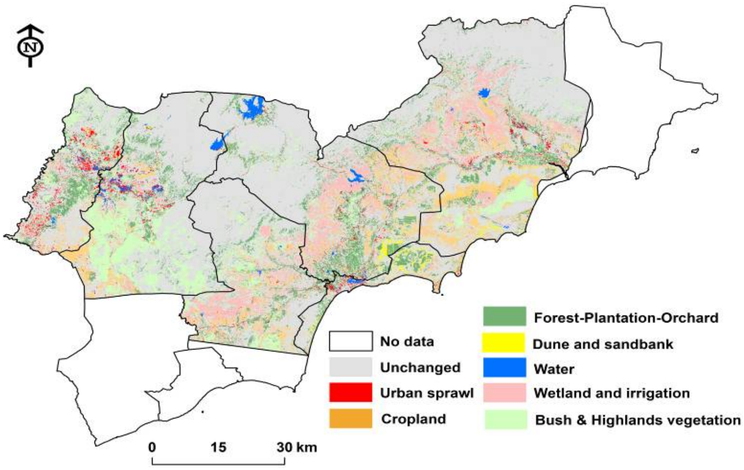

Fig. 4: Change detection map for the studied area (spatial extends of converted classes are highlighted).

TABLE 5: AREA AND PERCENTAGE OF CHANGE IN EACH LULC CLASS AND ANNUAL RATE OF CHANGE BETWEEN 1990 AND 2002

Change class		**Districts and city affected by changes**						**Total area (km²)**	**Change rate (%)**	
From	**To**	**Bac Binh**	**Duc Linh**	**Ham Thuan Bac**	**Ham Thuan Nam**	**Phan Thiet**	**Tanh Linh**			
FPO	HIB	91.3	46.6	40.6	76.4	0.5	237.5	492.8	21.1	49.1
	WET	136.2	8.1	75.6	82.7	2.0	20.1	324.6	13.9	
	CLD	98.3	34.8	57.7	30.3	2.4	58.4	282.0	12.1	
	BUP	4.5	15.6	3.6	2.0	1.5	6.1	33.4	1.4	
	WAT	2.3	2.7	4.6	0.8	0.2	3.9	14.4	0.6	
CLD	FPO	57.6	55.9	89.7	36.4	30.5	35.1	305.2	13.1	24.1
	WET	36.3	7.5	36.1	29.7	1.3	9.6	120.5	5.2	
	HIB	9.7	7.1	16.1	5.0	0.6	8.3	46.8	2.0	
	BUP	9.2	12.6	7.2	2.6	2.7	9.4	43.7	1.9	
	DSB	9.7	0	8.4	0.3	10.3	0.0	28.7	1.2	
	WAT	2.3	3.0	3.7	0.5	1.2	6.2	17.0	0.7	
HIB	FPO	70.2	11.7	55.3	27.1	2.0	44.0	210.3	9.0	14.4
	WET	30.9	0.1	18.0	5.4	0	3.2	57.7	2.5	
	CLD	25.0	0.3	5.9	1.3	1.1	4.1	37.7	1.6	
	WAT	3.4	1.4	16.7	0.3	1.5	6.7	30.0	1.3	
WET	CLD	30.4	0.6	19.2	33.7	0.9	1.3	86.1	3.7	7.0
	FPO	8.9	2.8	8.5	10.2	0.2	2.8	33.5	1.4	
	HIB	6.9	0.4	6.5	13.2	0.1	6.2	33.3	1.4	
	BUP	2.5	0.5	0.9	1.4	0.1	0.4	5.8	0.2	
	WAT	1.9	0.7	1.6	0.6	0.2	0.4	5.5	0.2	
DSB	CLD	29.7	0.2	5.8	1.7	13.2	0.2	50.7	2.2	2.7
	FPO	4.7	0.8	2.4	0.5	3.6	0.4	12.4	0.5	
BUP	FPO	7.8	6.4	6.7	3.2	1.2	1.1	26.4	1.1	1.7
	CLD	4.2	0.7	3.5	2.0	0.8	1.3	12.5	0.5	
Total (km²)		683.9	220.5	494.5	367.0	78.1	466.8	2310.9	99.0	99.0

In 21.1% of the cases the change was ‘‘Forest to wildland with spare vegetation” and approximately 14% was “forest to irrigated agriculture’’ change. Table 5 also reveals that residential uses comprise over half the cases that changed to urban. Relatively rare and unlikely types of conversions, such as agriculture to forest, and then to urban uses and forest to agriculture, and then to urban, totaling 5%, are assumed to largely be classification errors. The spatial interpretation of these results indicates that urban increases (BUP) mainly came from conversion of FPO, CLD and WET classes (representing 80.2% of the change rate). Overall, 82.8 km² of built-up was converted from forests and agricultural land (rainfed: CLD and irrigated: WET), while at the same time, 39 km² of urban or rural settlement land was converted to forest and cropland. These changes may seem to be classification errors, but forested areas are among some of the most sought after areas for developing new settlements. Streets, roads and rural tracks were generally classified as urban, but when urban tree canopies along the streets grow and expand, the associated pixels may be classified as forest. Also, the results of image interpretation and classification together with an access to archives on agricultural policies indicated that an intensive development

programs have been implemented in the study area during the last two decades [29]. These programs included land reclamation and the expansion of irrigated culture areas, as well as the establishment of rural village communities into foothills of mountains previously considered as wild-lands or unused lands. Further GIS analysis revealed a strong relationship between new development and proximity to roads. Almost half (49%) of the Built-up development detected in our classifications occurred within 2 km of main roads and rural tracks, and 35% was between 2 and 4 km. Duc Linh, Tanh Linh, Bac Binh and Ham Thuan Bac are the districts where this urban sprawl is the most remarkable during the studied (1990–2002). All of these (bio) physical changes within the setting of the region's ecosystems reflect the dynamics of human impacts on the study area.

Cropland (CLD) area declined from 1332.2 km² in 1990 to 1240 km² in 2002. This class was mainly changed into planted vegetation (FPO), irrigated land (WET), Brush (HIB) and Built-up accounting for almost 22% of the total occurred changes. Ham Thuan Bac, Bac Binh and Duc Linh are the districts mainly affected by this kind of conversion.

The area of water bodies plays an important role in development of aquaculture for the study area. During the studied period, water body increased by about 6.5 times of the original area. Water occupied 13.2 km² (0.2% of total studied area) in 1990 and finally reached 80.5 km² (1.3%) in 2002. This was converted mainly from natural forest, planted vegetation (FPO), cropland (CLD), bush (HIB), lowland and paddy fields (WET). The most plausible explanation of this conversion into water bodies was mainly due to hydroelectric dam constructions (Bac Binh, Ham Thuan Bac Tanh Linh districts) and also probably to expansion of small reservoirs for irrigation.

Lowland with irrigated agriculture fields (WET) also showed increasing trends in size from 1990 to 2002. The area of paddy fields was only 296 km² (4.9% of total area) in 1990, increased to 637 km² (10.5%) in 2002. This class extends on the foothill of the mountain chains and chiefly into hilly valleys following geographical orientation of the alluvial basins. This was converted mainly from natural forests (FPO), cropland (CLD) and HIB class vegetation and some from water bodies and mixed orchard.

Even though many hectares of natural forests were converted into planted vegetation and other agricultural land from 1990 to 2002, there was also conversion from barren lands to cropland and forests. This change occurred on dune and sandbak (DSB) class where decrease occurred from 141.9 km² to 110.4 km². These areas are used primarily for horticultural activity, with only very small areas of rain-fed rice grown in low-lying areas. Another explanation of this reverse trend is that there was a wide application of vetiver grass (*Vetiveria zizanioides*) planting that has real impact on land stabilization / reclamation. Although the concept of using vetiver for various applications has only been introduced into Vietnam in 1999 [17] vetiver has become widely known throughout the country with numerous successful applications for natural disaster mitigation and environmental protection. Typical examples include road batter stability enhancement, erosion / flood control of embankments, dykes, riverbanks, sand dune fixation. However, we can unfortunately notice a persistence of sandbank and dune roving, resulting probably of land degradation in Bac Binh (9.7 km²), Ham Thuan Bac (8.4 km²) districts and Phan Thiet (10.3 km²).

IV. DISCUSSION

Within a few years, Vietnam was not only producing enough food for domestic consumption but became one of the world's leading rice exporters [29]. Unfortunately, in some regions, farmers profited much less from the reforms than others. There is wide disparity in regional development trends following land reforms partly because the reforms were not implemented homogeneously throughout the country and also because of the tremendous diversity of natural and human environments they were applied to. This resulted in different ways of interpreting local success or failure of the land policy to lift marginal farmers out of poverty or reverse land degradation trends [30]. Land use in the study area has undergone dramatic change and was impacted by human resource development. Our findings from the satellite-image interpretation suggest a decrease in closed canopy forest due to conversion into rain-fed and irrigated agricultural land. Open canopy forest cover (including bush and fallows) increased during the 1990s approximately by 4%, mainly due to the natural regeneration of mixed grassland. Followed fields formerly used for shifting cultivation may be largely abandoned during the last decade and regenerated to become open canopy secondary forest. Overall, rain-fed mixed agriculture decreased slightly in the 1990s, as the reduction in shifting cultivation was compensated by an expansion of irrigate cropping area. Water bodies also showed increasing areas from 1990 to 2002, but the overall change was not large for these types. Increases in irrigated fields and water bodies represent the possibility of increasing aquaculture or increasing the suitability of the study area for future aquaculture. It has been demonstrated that in terms of economic returns, aquaculture often gives higher returns than rice culture [31]. However, the decision to convert paddy fields to fish ponds is often related to food security and social aspects. In order to maintain a balance between social and economic aspects, integrated rice-fish culture systems should be promoted [32]. Outreach and extension services to local farmers should be enhanced, and extension information should be produced. Over time, agricultural production became more locally concentrated. These changes in land use suggested that shifting cultivation as the traditional farming system practiced by the population in the research area almost entirely disappeared in its traditional form during the last decade. On the other hand, provincial and district authorities generally lack of manpower, resources, capacity and experience to put into practice consistent and participative land-use policy. They should be allocated more resources and more time to implement a policy that would satisfy the different objectives expressed at different hierarchical levels. Experience has shown that promoting the links between land allocation and subsequent extension activities is indispensable for close interaction with farmers and when directing research to development activities that are relevant and acceptable to local people. In a broader context, some studies are summarizing the general factors that promote a successful transition towards sustainable management of natural resources [33]. Three broad groups of factors that have been identified: information regarding the state of the resources and their degradation, motivations to search for solutions, and capacity to implement effective solutions. Environmental degradation of places with which people maintain an emotional connection can lead these people to adopt a more ecological worldview and to reassess their involvement in conservation activities ([34]; [35]). The perception of the capacity to predict and improve the state of the environment also mediates behavior [36].

Overall, natural forests declined in area, while the most dramatic increase was for irrigated fields. During the 12-years span, we can observe a pathway of land expansion into previously uncultivated areas. At the same time, due to market development, agricultural intensification is concentrated in the most suitable regions. Large areas of land marginally suitable for agriculture are therefore abandoned and left to forest regeneration. In this forest scarcity path, political and economic changes will arise as a response to the growing scarcity of forest products and decrease in the provision of ecosystem services following. We think it is possible that intensification of agriculture combined with the (enforced) protection of forested areas can reduce the pressure on forested land, and slow down or even halt the expansion of agricultural land if coupled with the right policy instruments.

Concerning the undesirable changes in land use and the need for more sustainable development in the region, we propose that the government should reconsider the policies applied to the region of the study area, as well as the policies of the surrounding regions that may directly or indirectly affect the development of the study area. For instance, the modeling power of GIS to evaluate land suitability for development of agricultural activities chiefly in the basins and watershed ponds must be developed. It is known that sustainable agricultural systems are based on managing soils according to their capabilities and environmental constraints. According to this, GIS information could allow the landholder to move from regional or district land suitability recommendations and land management practices to soil-specific management, thus improving productivity, profitability and sustainability. An economic component should be incorporated into GIS applications to determine economic suitability in addition to physical suitability. This would reduce the cost of the rehabilitation of degraded and barren areas and, consequently, facilitate the adoption of more ecological worldview and less vulnerable of land conservation activities. In addition, to lessen the degree of degradation, the free water areas should be reduced, or at least consolidated. This could be achieved through the improvement of the drainage network system in the waterlogged areas and by preventing drainage water from overflowing into lowlands. These actions could protect cropland areas from soil salinization and, consequently, increase agricultural production, especially in order to adapt to future impacts of climate change [37].

V. CONCLUSION

The results demonstrate that Landsat classifications can be used to produce accurate landscape change maps and statistics. General patterns and trends of land use change in Binh Thuan Province were evaluated by: (1) classifying the amount of land in six districts area that was converted from forest, agricultural, and wetland use to urban use during three periods from 1990 to 2002; (2) comparing the results of Landsat-derived statistics; (3) quantitatively assessing the accuracy of change detection maps; and (4) analyzing the major land use change patterns. In addition to the generation of information tied to geographic coordinates (i.e., maps), statistics quantifying the magnitude of change, and ‘‘from–to’’ information can be readily derived from the classifications. The results quantify the land cover change patterns in Binh Thuan Province and demonstrate the potential of multitemporal Landsat data to provide an accurate, economical means to map and analyze changes in land cover over time that can be used as inputs to land management and policy decisions. While it is a site specific comparison, it is also useful to compare the Landsat classification estimates to another, independent inventory such as the Natural Resources Inventory. Perfect agreement would not be expected due to the differences in the dates of data collection, as well as differences in classes between the two surveys.

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