GISDECO 2004: Seventh International on GIS in Developing Countries,
Universiti Teknologi Malaysia, Skudai, Johor, Malaysia, 10-12 May 2004

Developing A Versatile Land-Use Information System Based on Satellite Imagery for Local Planning in Indonesia Phase I: Establishment of Classification Scheme

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Abstract

Local planning in Indonesia is currently suffering from a lack of data and poor planning coordination. This situation is due to the absence of up-to-date, accurate, relevant and reliable land-cover/land-use (LC/LU) and other thematic maps, which should be used as a set of common reference by various local planning authorities. Although many local governments have established a so-called Key Dataset for Local Development (KDLD), in which the LC/LU and other relevant information are stored, they do not routinely apply this information. Within the KDLD the LC/LU information is considered to have very low reliability for supporting planning. This is because many institutions developed their own maps with different: classification schemes; data sources and scales; and survey methods. Consequently, redundant LC/LU surveys of the area are carried out to ensure that the collected LC/LU maps to be used contain relevant information for local planning. To address this problem, a versatile land-use information system (VLUIS) was developed. The VLUIS uses remotely sensed imagery as the main data source. A classification scheme was developed using multi-dimensional approach, by which various attributes of LC/LU classes, i.e. spectral, spatial, temporal, ecological and socio-economic function, are used to define land-use categories. A questionnaire-based survey involving 36 stakeholders in the study area was carried out in order to collect required information that needs to be presented in the scheme. By storing the resultant LC/LU map within GIS queries of a robust and relevant land-cover map are able to be used to support various applications relevant to local scale planning. This paper discusses the development of the versatile land-use classification scheme and its implementation through an automatic classification of satellite image data to map LU information. Landsat-7 Enhanced thematic Mapper Plus (ETM+) and Quickbird imagery covering the Semarang area, Indonesia, with 30 m and 2.4 m pixels were used for the mapping. Future research needs for accomplishing the image classification and other spatial data processing for all dimensions are also discussed.

Introduction: Background and Problem

Regional development planning is a set of activities to allocate resources in space so that the region of interest may economically, ecologically, and socio-culturally gain more benefit. Kannegieter (1988) stated that in development planning activities a land-use survey frequently forms an integral part of a survey project to provide information for relevant database. Lindgren (1985) underlined the importance of land-use information in planning as a crucial element.

Unfortunately, land-use information is still difficult to obtain when quality, relevance, and newness are considered as major criteria. Fresco (1994) claimed that accurate data on land-use and land-use changes are not easily found, both in the global and continental scales as well as the national and regional ones. Indonesia is an example, where land-use information is developed by various institutions with overlapping authorities and non-systematic ways of updating. These may lead to the production of land-use information or maps that are incompatible to each other and cannot be used as a common reference for planning

In order to support planning, remotely sensed imagery have been used as a major source of land-cover (LC) and land-use (LU) information worldwide (Stibig, 1997; Stefanov et al., 1999; Campbell, 2002; Tapiador and Casanova, 2003), even though Indonesia’s National Land Agency (BPN) has not systematically applied this at operational level. In many countries, research carried out in landscape ecological and land evaluation context show that remote sensing plays an important role in derivation of LC and LU information (Forman, 1995; Conacher and Conacher, 2000; Zonneveld, 2001). Regional and urban planning activities in many countries also make use of land-use information, which is frequently derived from remotely sensed data (Bouma *et al.*, 1998; Carlson and Sanchez-Azofeifa, 1999; Zhang, 1999). In Indonesia, however, the use of remotely sensed data in urban and regional planning is still limited to academic research and *ad hoc* survey activities, except in several large cities.

Various techniques in remote sensing can derive LC and LU information content with a great diversity. Van Gils *et al.* (1990) explained the differences between LC and LU. From remote sensing point of view, Campbell (2002) stated that LC is concrete while LU is more abstract. They also emphasised the importance of making separation between LC and LU in any land-use map. However, several classification schemes intentionally exchange both concepts (e.g. Anderson et al., 1976; Malingreau and Christiani, 1982; Sandy, 1982). Visual interpretation could directly derive both LC and LU information at certain level of scales, but digital image processing that is not supported by GIS analyses can only generate LC classes. Thus, under this circumstance, LC and LU maps of the same area may represent different information, which may lead to users’ confusion in planning.

Problems and situation described in the aforementioned paragraphs exist in Indonesian planning program, particularly at provincial and local level. Suroso (2000) described a three-tiered hierarchical plan for development planning, namely national, regional and local levels. The local level is mainly characterised by “more land-use oriented” programs such as land-use zoning, allocations, conservation and measures parallel with coordination and implementation of policies. On the other hand, the provincial and local authorities have developed a so-called *Data Pokok untuk Pembangunan Daerah* (Key Dataset for Local Development, KDLD) containing a set of maps to support a range of planning activities. It was found that the quality of maps stored in the KDLDs is not adequate to support planning tasks due to their newness, accuracy, and relevance.

Among others, LC/LU maps are recognised as important information with the lowest reliability due to their low quality. As a consequence, each institution tends to develop its own LC/LU information with limited consultation to the others. Therefore, redundant works on LC/LU surveys take place and incompatibilities between maps partly covering the same areas come up.

Based on this current situation, problem associated with the local planning in Indonesia can be viewed from the spatial information point of view, i.e. the need for developing up to date, accurate and relevant information on LC/LU to support local planning tasks in Indonesia. To solve such a problem, efforts should be carried out in conjunction with the advances in remote sensing technology, which can deliver a range of remotely-sensed data required by various local planning tasks.

Study Objective And Goals

The objective of this study was to develop a satellite image-based land-use classification scheme, which is versatile in character so that may support various local planning tasks in Indonesia. In order to reach its versatility, a couple of goals were set up: (a) specification of physical planning tasks at local level requiring LU information, (b) problems identification in developing, using, and maintaining LU information for various applications, (c) design of versatile LU classification scheme as a part of the development of versatile land-use information system (VLUIS), (d) Examples of the first dimension of the VLUIS moderate resolution Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Quickbird high-spatial resolution satellite imagery covering Semarang area, Indonesia.

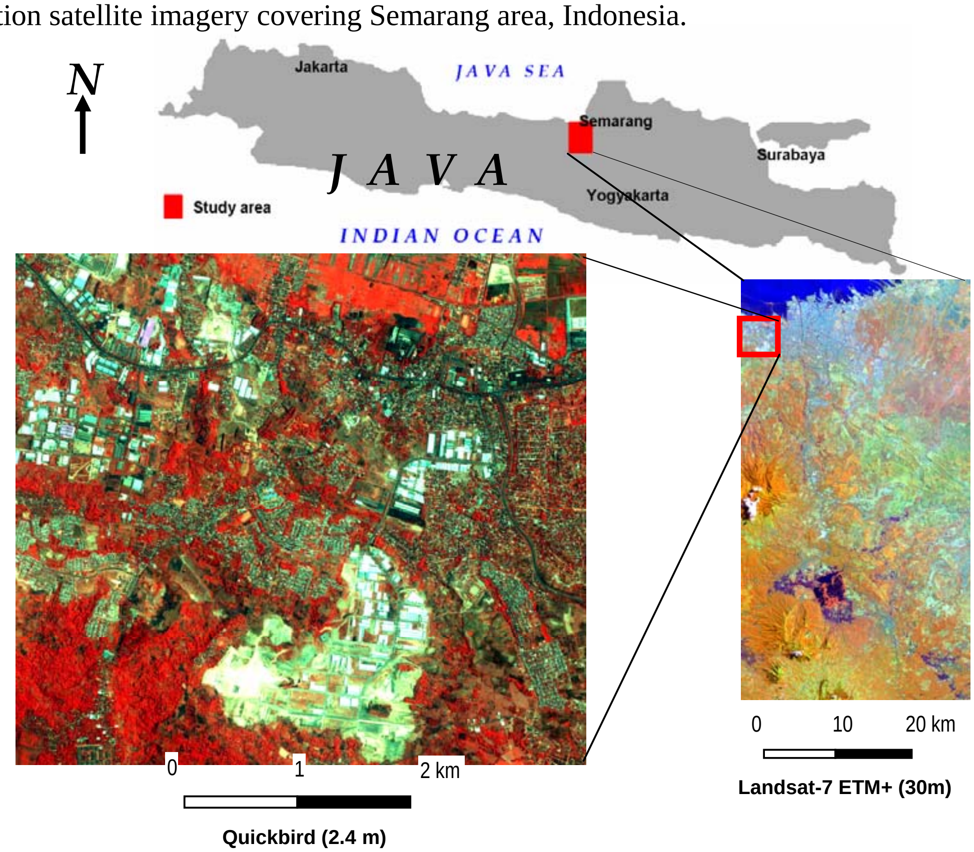

Figure 1. The study area as shown on Landsat-7 ETM and Quickbird images.

This study is a part of a large, longer term research aims at developing versatile LU classification scheme and information extraction methods for each category within the scheme, followed by demonstration in applying the obtained spatial data to support several local planning tasks.

Previous Works

Studies on the development of LC/LU classification systems have been carried out by various authors. One of the most eminent systems is the USGS LC/LU classification system (Anderson *et al*., 1976), which mixes up LC and LU terms in its categorisation. The USGS LC/LU classification system is widely used in various projects in the USA. For Indonesian environment, Malingreau and Christiani (1982) and Sandy (1982) also developed system mixing up LC and CU concepts. Similarity between the systems is that they establish a multilevel/hierarchical classification to be applied on different resolutions or scales.

The USGS system has been criticised due to its resource-oriented (LC) approach as compared to the Standard LU Coding Manual (Jensen, 2000). Another classification system emphasizing on the people activities with hierarchical approach is the Land-based Classification Standard (LBCS) being developed by the American Planning Association (1999, in Jensen, 2000). Van Gils *et al.* (1991) also criticised the USGS classification system due to the unclear differentiation between LC and LU. They also proposed a two-level 'ITC World LC and LU Classification', which tried to separate LC from LU categories and simultaneously established relations between the two. Recent development of LC/LU classification systems were undertaken by Food and Agricultural Organisation (Jansen and Di Gregorio,1998), Young (1998) and Cihlar and Jansen (2001). Young's classification was purposively developed to describe the modification level of the land by human activities, so that it might suite to land-resource based or agricultural planning.

Similarity between all aforementioned classification systems is their single attribute for each category on each level. The single attribute of LC/LU categories may become problematic at the subtler level, e.g. level III and IV of the USGS classification system, since more detailed information in a single attribute tends to be more specific. As a consequence, it is more difficult to use similar categories under different schemes for practical purposes, e.g. monitoring of land-use change. That is why Young (1998) emphasised the need for development of LU classification system containing multiple attributes comparable to soil properties found in the World Reference base for Soil Resources.

In terms of methods of mapping using aerial photographs, van Gils *et al.* (1990) described three approaches commonly used, *i.e.* photo-guided, photo-key, and land-ecological approaches. The photo-guided only uses photo as a basis for field orientation with no interpretation. The photo-key mainly uses photomorphic approach to interpret features on the imagery, while the land-ecological approach tries to integrate information on terrain/lad characteristics with the LC features appearing on the imagery so that LU information can be derived.

By using digital satellite imagery, multispectral classification can automatically derive LC-related spectral classes (Jensen, 1996; Mather, 1999). The tentative categories can then be regrouped and relabelled into more meaningful LC classes. Liu *et al.* (2002) suggested the combination of various automatic image classification methods, *i.e*. maximum likelihood, expert system, and artificial neural network for improving land cover map accuracy. In order to derive subtler information on LC or LU, per-pixel image classification can also be integrated with contextual information (Stuckens *et al*., 2003), such as landscape characteristics related to soil properties and slope steepness (Folly, 1996; Danoedoro, 2001; Ehlers *et al*., 2003).

In order to optimise the use of remotely sensed data for land management and planning , an objective and replicable framework to guide the operation is essential. Phinn *et al.* (2000) demonstrated how such a framework was developed for coastal environment. Phinn *et al.* (2002) undertook similar study in optimising state of environment monitoring at multiple spatial scales of remotely sensed data. In their study, identification of environmental type, cost and time constraints, required information (scale, error tolerance), and specified processing techniques were used as the main input to the framework. This input was then matched with the specification of ideal data in order to derive the output, i.e. evaluation of suitable remotely sensed data and suitable analysis methods for monitoring, modelling and management of coastal environment. This framework gives an idea that the development of reference systems, including classification schemes, to be used for particular or general tasks should be started from the bottom, i.e. problems identification, required information, and specification of available data sources.

Methods

Methods developed for this study was divided into two parts: (a) questionnaire-based survey for collecting data from the stakeholders, and (b) versatile land-use classification scheme development based on analysed questionnaire, satellite image specification, and relevant previous works. Following the classification scheme, examples of classified image derived from automatic classification are given to demonstrate a stepping stone for further information extraction.

<u>Questionnaire-based survey</u>

Types of questions

A list of questions in a questionnaire was prepared to collect information on (a) perception about aims of planning, (b) scope of physical planning, with an emphasis on local level, (c) roles of institutions in local planning, (d) factors determining the success of physical planning (e) problems identified, both organisational and data use, (f) spatial data required to support planning, focusing on the KDLD and its problems, (g) land-use issue: availability, quality, and problems in its use, (h) examples of local planning tasks that utilise LC/LU information. Nearly all questions were given with closed answers, at which the respondents could choose the most suitable degree of agreement (*e.g*. ranges from fully disagree to fully agree; no problem to very serious problem). Only a few questions were given with yes/no answers, while the others were given with open answers.

Target group

A group of people representing various parties involved in planning at various level of planning was interviewed in order to specify the physical activities related to local planning. The stakeholders comprise local government staff representing various local institutions related to planning, research group/consultants, university-community partnership, non-governmental organizations (NGOs), and non-affiliated local people. People from provincial and central government institutions were also involved since those bodies have played very important part in designing planning guidance and specifying the data types, quality, as well as map scale to be used at various level.

A total number of 36 persons were interviewed, even though the main concern of this survey was institutions rather than individuals. The respondents were allowed to response with any assistance from their colleagues. Table 1 shows the distribution of number of people according to the institutional levels and roles.

Analysis methods

The questionnaires were not analysed statistically. Rather, they were evaluated qualitatively due to the following reasons: (a) some questions, particularly the critical ones are given in open way, *e.g.* local planning tasks they have been doing accompanied with supporting documents (classification systems, approaches, methods, required data, and data types); (b) the number of respondents to be interviewed is relatively small, and they will be treated unequally, based on the assumption that they play different roles in planning, *e.g.* staff at Bakosurtanal and local Bappeda as compared to those at other local offices. This method is summarised in Figure 2.

Tabel 1. Distribution of respondents according to the types of institutions and scopes of operation

Institutions \ Level	Central Government	Provincial Government	Local Government	Other Local stakeholders	Total
National Coordinating Agency for Surveys & Mapping	4				4
Directorate General for Regional Development (Bangda)	1				1
Ministry of Settlement and Regional Infrastructures	4	1	1		6
Bappeda (Regional/local development planning agency)		4	5		9
National Land Agency (BPN)		1	1		2
Ministry of Forestry		2			2
Local Agricultural Office			1		1
Local Centre for Electronic Data			1		1
Research consultant/expert group				5	5
University consultant				2	2
Non-government organisation (NGO)				2	2
Local people				1	1
Total	9	8	9	10	36

Development of Classification Scheme

Findings obtained from the questionnaire data was analysed together with previous works dealing with land-use based environmental assessment and modeling. In addition, several classification schemes widely used such as USGS LC/LU classification systems (Anderson *et al.*, 1976), LC/LU classification system for Indonesia (Malingreau and Christiani, 1982), ITC (van Gils *et al.*, 1991) were taken into account. Moreover, various concepts related to LC, LU as viewed from spectral, spatial, temporal, ecological, and socio-economic aspects were also considered. These include spectral characteristics of various objects (Hoffer,1978;Curran,1985;and Jersen,1996); spatial pattern and geographic position/site (Lillesand & Kiefer,2000); temporal pattern of LC and LU (Van Gills et al.,1990; Kannegieter,1988); tropical ecology (Ewussie, 1990; Osborne.2000); and socio-economic aspect of LC and LU (Sutanto,1986; Jensen,2000)

Since a multilevel classification is considered more suitable for local regions in Indonesia, which show a wide range of areal coverage, various satellite imagery with various spatial resolutions were considered. Previous works using various satellite data were reviewed with respect to the level of details of the categories generated, methods of processing used or developed, and accuracy levels reached. The work of Phinn *et al.* (2000) was also taken into account. Meanwhile, types of information to be included in LU categories were also specified with respect to the previous works in environmental application, such as erosion modelling, ground water pollution, crop production estimates, industrial site selection, and land compensation.

Since the versatility to be developed in this study is multidimensional in character, a framework of the LU multidimensionality was established (Figure 3). In this diagram, LU is considered as a multidimensional concept that can be viewed from various perspectives, *i.e.* spectral, spatial, temporal, ecological, socio-economic value, and political/legal. Description of each dimension can be found in Table 2.

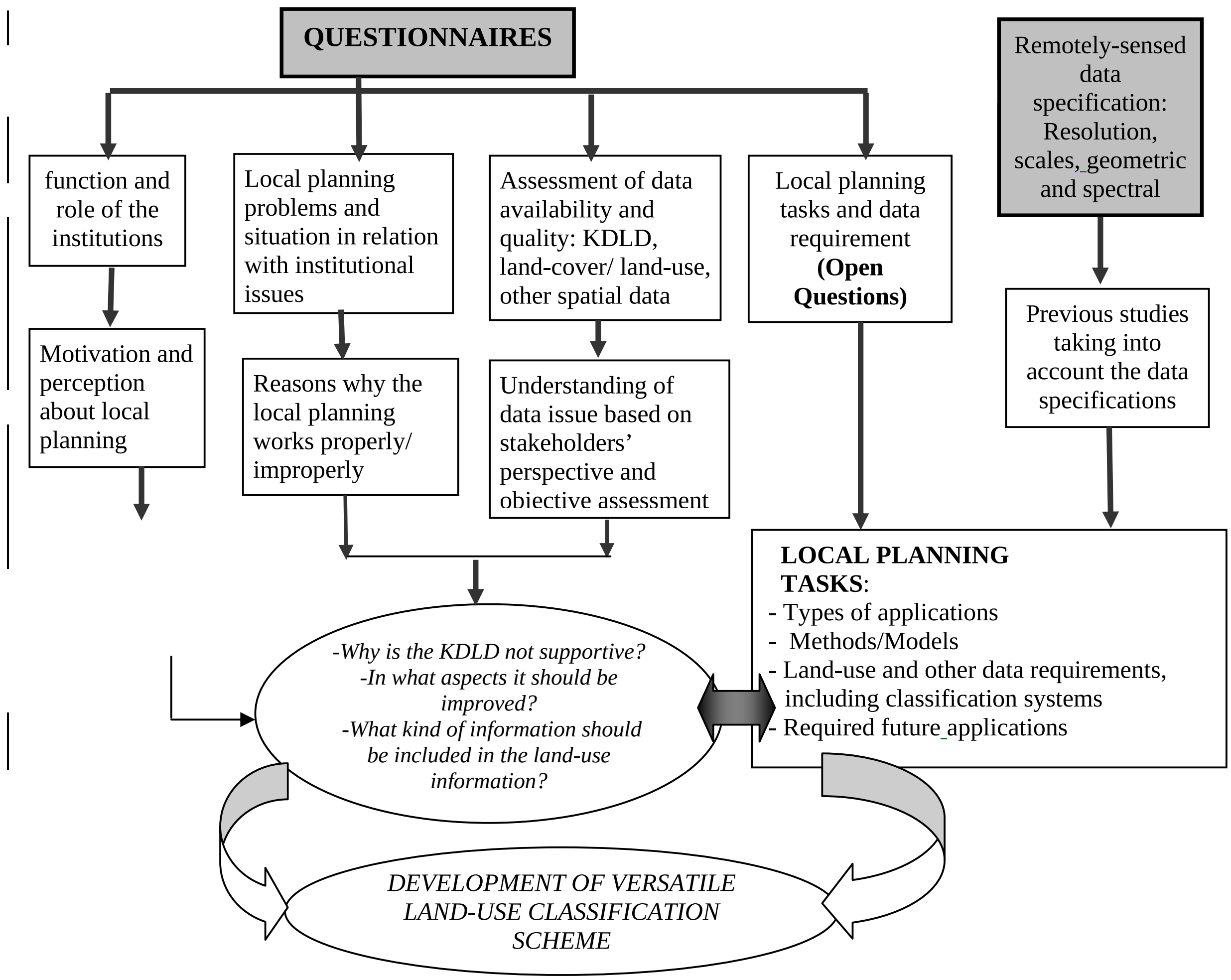

Figure 2: Method for analysing the questionnaire as a basis for specifying local planning tasks and their link to the development of versatile land-use classification scheme

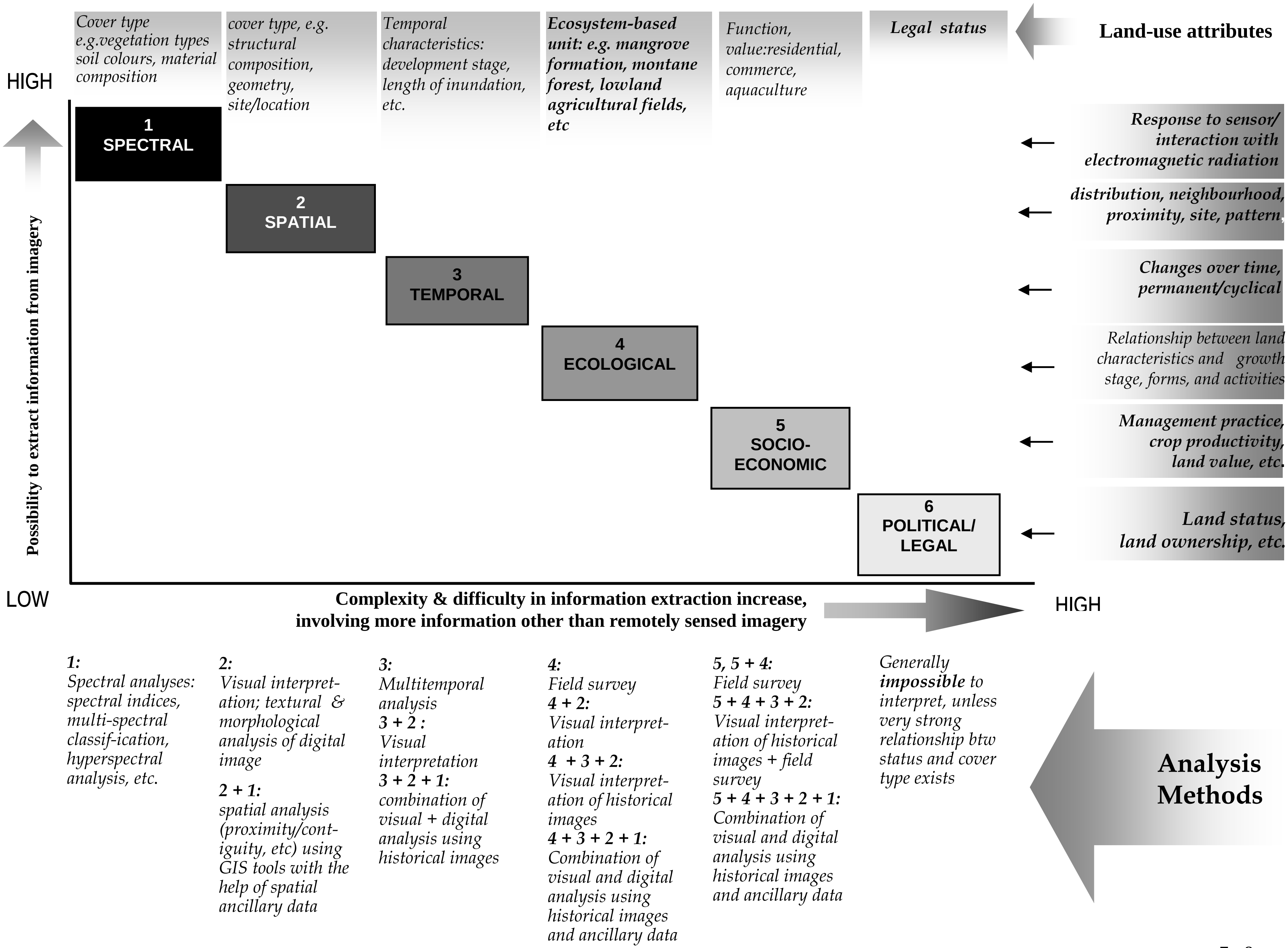

Figure 3. Dimensions of land-use (shown as boxes 1-6) as viewed from remote sensing and GIS perspective

Table 2. Description of each land-use dimension used in this study

LAND-USE DIMENSION	DESCRIPTION
Spectral	Strongly related to, or may directly be identified based on, spectral information of the objects. In general, the spectral dimension is expressed by cover type
Spatial	Related to particular spatial pattern or arrangement, position or site, which is normally used as an additional key factor (besides spectral dimension) to distinguish one feature from others, e.g. river, lake, regularly spaced stands, interleave planting, coastal mudflat
Temporal	Related to temporal or seasonal changes, e.g.. length of indundation and crop rotation. Information related to spectral and spatial aspects is also required to determine temporal dimension.
Ecological	LC and LU forms express interaction between vegetation, animals and human activities with the land they exist. Their existence also represent the environmental characteristics of the area, e.g. mangrove formation, upland agriculture, slum areas
Socio-economic	Basically, many land-cover types and land-use functions have economic or socio-economic functions too. However, the socio-economic dimension needs to be explicitly presented, if they have.
Legal	Basically it is difficult to extract using remotely sensed imagery.

Image analysis and classification

Image classification was run in order to apply the classification scheme. In this study, the first (spectral) dimension of the versatile land-use information was derived using image processing software. As the study is still going on, other dimensions were demonstrated using visual interpretation or other standard procedures in image processing.

Data and softwares

Two image dataset were used in this study, i.e. Landsat Enhanced Thematic Mapper Plus (ETM+) bands 1-5 and 7, and Quickbird bands 1-4 and panchromatic. The ETM+ imagery (path/row 120/065) was recorded on 21 August 2002, while the Quickbird imagery was recorded on 31 August 2002. The whole area covered by the Quickbird is also covered by the Landsat. In this study, two image processing softwares were used, i.e. ENVI 4.0 for most processing tasks, and ERDAS Imagine 8.6 for particular ones. The ENVI software was mainly used for making image subset, selecting samples through regions of interest (ROIs), assessment of samples' statistics, execution of multispectral classification and assessment of classification accuracy. The ERDAS Imagine was mainly used for multiresolution image merging, image reprojection, and resampling.

Analysis

During the first stage, each image dataset was treated differently. After geometric correction and subset cropping, the Landsat ETM+ data was prepared for multispectral classification. Meanwhile, a multi-resolution merging of Quickbird imagery using Brovey transform (Vrabel, 1996) was carried out in order to create a new colour composite imagery with higher spatial resolution, *i.e.* 0.60 m with four combination from newly transformed bands: Band 1+P, Band 2+P, Band 3+P, and Band 4+P. The original Quickbird multispectral image dataset was also preserved for multispectral clasification.

Image classification was performed in three stages. Firstly, ROI-based sampling that was performed interactively. Selection of ROIs was mainly based on the collected field data, even though some additional ROIs were chosen based on local knowledge, topographic map as well as available aerial photographs. ROI names were given with respect to the prepared classification scheme with a slight modification, e.g. shallow water1, shallow water2, high density broadleaves on shaded areas. Every time a ROI is chosen, the sample statistics were evaluated and the class separability between existing ROIs was also calculated. Especially for Quickbird image dataset, the ROIs selection was also guuded by the display of Brovey-transformed multiresolution imagery. By doing so, homogeneity within each ROI could be evaluated directly, both visually and statistically.

Secondly, image classification and refinement using class merging. Image classification was performed using maximum likelihood algorithm. Prior to the classification execution, computation of statistical separability between classes was done using transformed divergence and Jeffrey-Matushita indices (Jensen, 1996). Thirdly, post-classification using selective majority filtering was applied in order to aggregate pixels of patchy classes into most common label within a given window, and to simultaneously preserve particular classes that are considered minority within a given window (*e.g.* linear features with 1-2 pixels width). By this selective majority, a pixel-based generalisation can be applied without losing important information conveyed by particular individual pixels.

Derivation of other LU dimensions

For this study phase (Phase I), the main goal of this study was the establishment of classification scheme for Versatile Land-use Information System (VLUIS). Derivation of LU spectral dimension in terms of LC type maps was emphasised to demonstrate the ability of automatic classification for LC mapping with currently developed classification scheme used as a reference. Therefore, other dimensions were tentatively demonstrated using visual interpretation.

Results and Discussion

The survey

Data collected via questionnaires were analysed in conjunction with in-depth interview with several persons having more experience in mapping and spatial information processing than other respondents. The following paragraphs illustrate several findings relevant to the development of the versatile land-use information system (VLUIS).

KDLD for local planning: current situation

Generally speaking, integrated planning is still difficult to achieve. Most respondents (72%) said that there are limited efforts to set up an integrated planning at local level. Only 3% of them said that the planning process is already integrated, while the others said that it is not integrated at all. Problems associated with that situation might be viewed from two perspectives: organisational and reference data. Although half of them did not blame the local coordinating agency for development planning (Bappeda), most of them (75%) agreed that there are no or limited cooperation between institutions in local planning. Moreover, 83% respondents agreed that there is no synchronised problem formulation among institutions as a starting point for planning. The absent of synchronised problem formulation is also recognised as the effect of no common reference data.

As viewed from the reference data perspective, the KDLD –which is purposively built by most Bappedas in Indonesia—is not used as a common reference. As shown in Figure 4, the main reasons for this are: out of date (88%), irrelevant information content (76%), and the low data quality (80%). It is surprising that such opinion came from respondents who are mostly staff at governmental institutions, who were institutionally involved in the development of the KDLD.

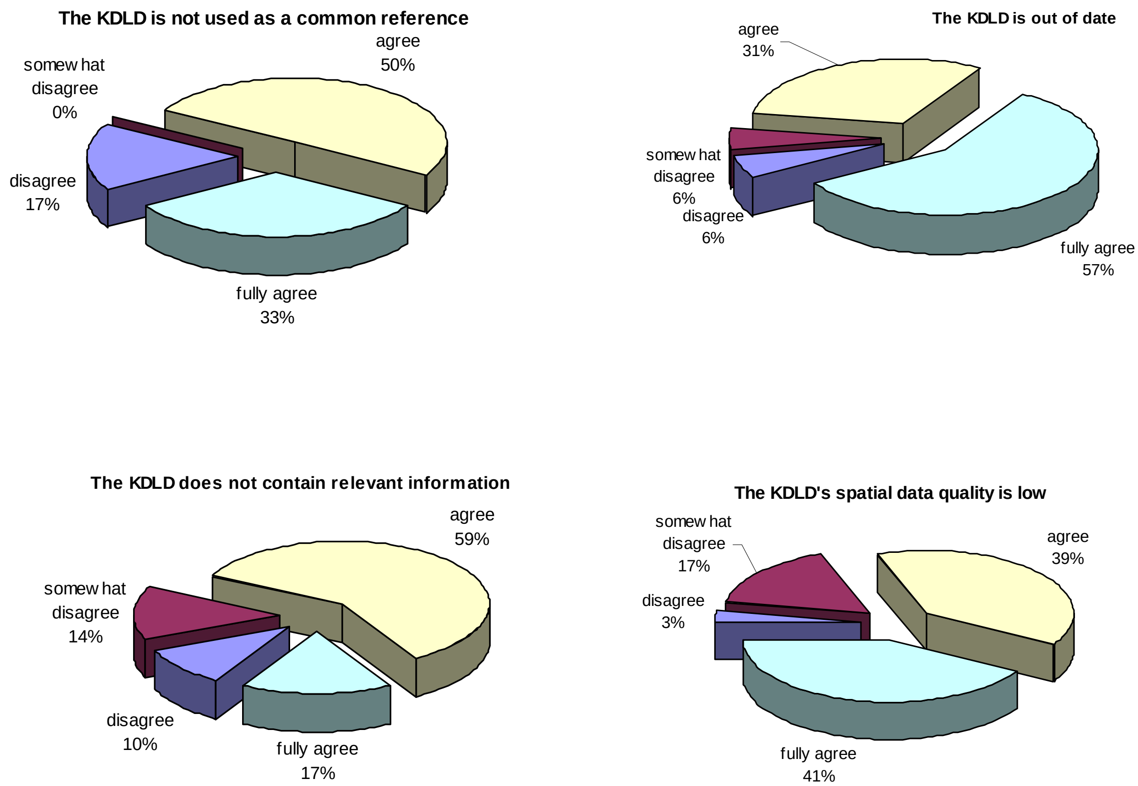

Figure 4. Problems in local planning associated with reference data

It is already known that spatial data quality has become a big issue in the field of geographic information. The respondents were also asked for their perceptions about data quality of various themes stored in the KDLD (Table 3). When the quality is categorised into ‘very poor’, ‘poor’, ‘good’, and ‘very good’, it was found that nearly all criteria of quality listed in the questions are considered poor-very poor. More than 60% of the respondents confirmed this. There was only one criterion, *i.e.* lineage/genealogy, considered as good-very good (57%).

Table 3. Quality of spatial data stored in the Key Dataset for Local Development according to respondents' opinion

No.	Aspects Of Accuracy/Relevance In The Context Of Local Planning	Perception of quality (% of the Respondents)			
		1 very poor	2 poor	3 good	4 very good
1	Accuracy: geometry	15	44	4	
2	Accuracy: classification result	32	47	21	0
3	Relevance: Classification scheme/ categorisation	7	64	29	0
4	Relevance: scale/resolution/level of detail	7	64	29	0
5	Completeness	4	60	36	0
6	Lineage/genealogy	18	25	46	11
7	Newness	14	61	18	7

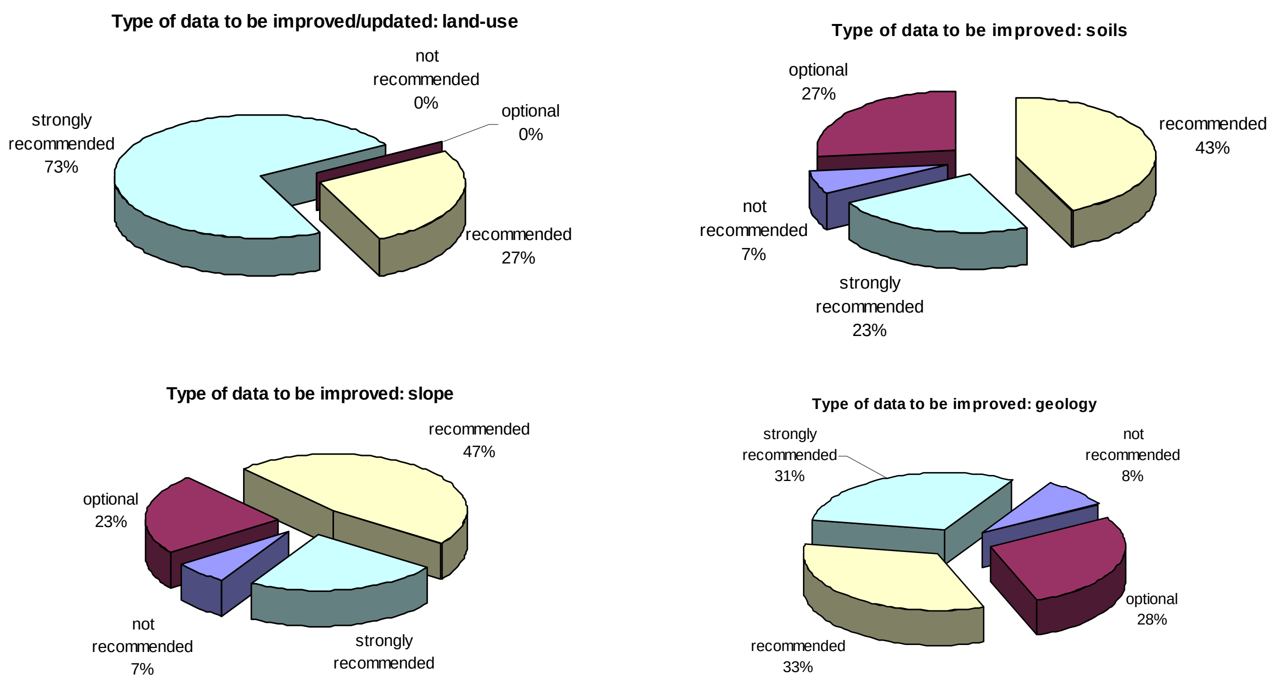

Figure 5. Respondents' opinion on the types of data requiring improvement

In terms of data themes within the KDLD requiring improvement or updating, LU information is the most important as compared to others (Figure 5). Most respondents (73%) strongly recommended LU information to be improved and updated, while the others (27%) also recommend it. About 7-8% respondents did not recommend improvement or upgrading of other themes such as soils, slope, geology, administrative boundary and topographic maps. This can be concluded that, among others, quality and newness in land-use information is a significant factor for local physical planning.

Land-use information in the existing maps: Problems and Expectations

Since LU is an important theme in the KDLD, specific questions about this were given in order to obtain perceptions from the respondents. Most respondents (93%0 agreed that LC and LU are different, although they are closely related. They also agreed (82%) that LC and LU information should be separated in classification schemes and maps. It is a response from the majority (88%) who found that LC and LU categories tend to mix up together in the existing maps. Furthermore, they also recognised (73%) that the existing or available LC/LU classification schemes and maps were purposively designed to satisfy particular applications. Figure 6 illustrates these findings.

Other important problems related to the development of LC and LU information to support local planning are (a) the availability of powerful remote sensing/GIS/global positioning system technology, (b) availability of skilled and trained staff in remote sensing and GIS, (c) bureaucracy, (d) up to date topographic/ base map, (e) availability of current remotely-sensed data including airphotos, and (f) budget. Table 4 shows how important each problem according to the respondents.

The respondents also recommended two other themes of spatial data, *i.e*. landform and digital elevation model, to be included in the KDLD. This is due to the fact that in many surveys related to physical assessment of the land, landform maps with Bakosurtanal's classification system are considered useful to describe geology/parent materials, relief, drainage density, and general soil characteristics.

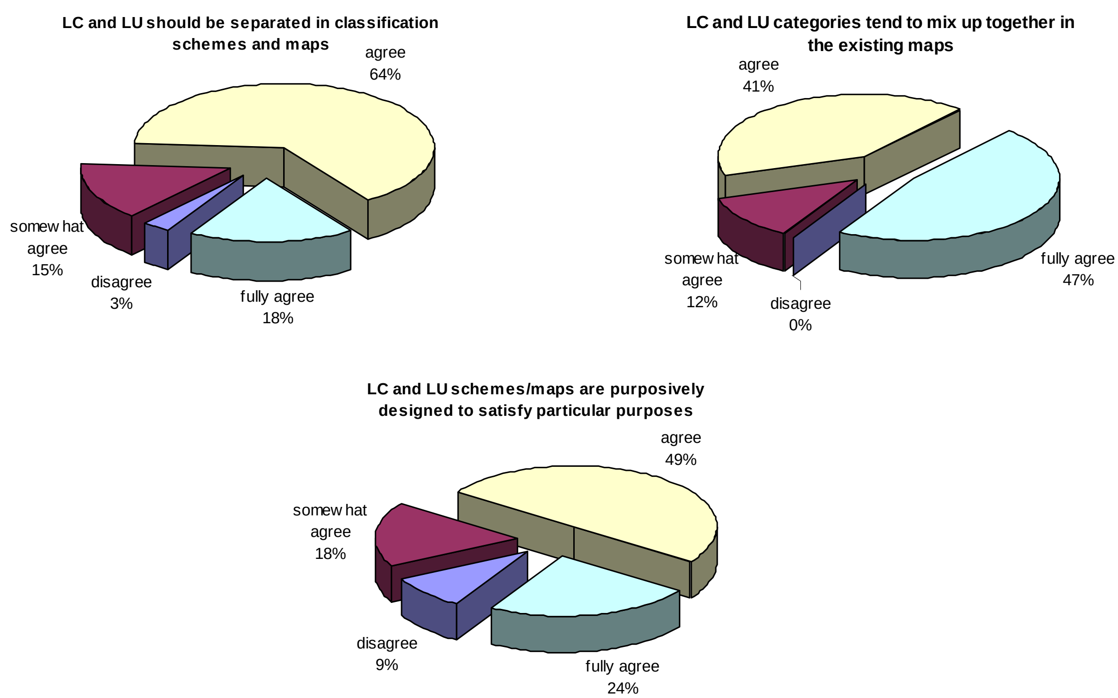

Figure 6. What should be done with the land-cover (LC) and land-use (LU) information?

Table 4. Respondents perception on the problems related to the development of LC and LU information for local planning

No.	Conditions That Are Potential To Be Problems	Perceptions (% Of The Respondents)			
		Not A Problem	Small Problem	Should Be Considered	Very Serious Problem
1	Availability of powerful technology to support surveys and mapping such as image processing, GIS and GPS	3	10	39	48
2	Availability of skilled and trained staff in remote sensing and GIS	0	36	35	29
3	Rapid change of land cover and land use	6	23	39	32
4	Bureaucracy	6	23	36	35
5	Availability of up to date basemap/topographic map	3	0	45	52
6	Availability of data source, *e.g.* airphotos and satellite images	3	6	32	59
7	Budget	0	10	51	39

In terms of information types associated with LC and LU, most respondents said that it is compulsory to include general cover types, spatial, ecological, socio-economic function and legal aspects in the LU map. However, less percentage was given to the more detailed cover types and temporal aspect. This is probably due to insufficient explanation about the meaning of each information type listed. Table 5 illustrates this explanation.

Table 5. Respondents' opinion on the importance of various aspects/dimensions of land-use to be included in any land-use map

No	Types of information related to land-. cover and land-use	Respondents' opinion (%)			
		Not recommended	Optional	Recommended	Compulsory
1	General cover types types (*e.g.* building, crop, bare soil, water body, etc.)	0	6	29	65
2	More detailed cover types (*e.g.* crop types, roof tile types, soil colours, etc.)	0	15	47	38
3	Spatial aspects: building density, spatial pattern	0	6	31	63
4	Temporal aspects, *e.g.* development stage, crop rotation	0	15	44	41
5	Ecological aspects, *e.g.* vegetation type (mangrove), tumpangsari, upland rural settlement	0	0	50	50
6	Socio-economic functions (commercial, business)	0	0	29	71
7	Legal aspect (e.g. land property/status)	6	9	32	53

Local planning activities requiring land-use information

A list of environmental applications related to local planning tasks is given below. It ranges from flood hazard risk mapping to facility management. Every respondent was asked to list and put emphasis on particular tasks if necessary. Table 6 shows the list of commonly done tasks related to planning and management of the land at local level. Grey scale on the list of activities indicate the frequency of the use of applications (light: seldom, dark: frequent), while the stars indicate importance level of information related to the land-use dimensions utilised in the applications.

Table 6. List of activities related to local planning tasks usually carried out.

No	Activities Related To Planning At Local Level Scale	Land-Cover And Land-Use Information Utilised				
		General Cover Type	Spatial	Temporal	Ecological	Socio-Economic
1	Flood hazard mapping	*	***	****	****	****
2	Pollution control	*	***	***	****	***
3	Waste disposal	**	****	**	****	****
4	Forest fire management	****	****	****	****	****
5	Impact assessment	**	**	**	****	****
6	Erosion mapping	****	****	****	****	****
7	Land capability analysis	***	*	***	****	****
8	Land suitability analysis	****	**	***	****	****
9	Crop production estimate	****	****	****	****	****
10	Site selection for urban planning	**	***	***	***	****
11	Spatial planning	**	**	**	****	****
12	Land use planning	***	***	***	****	****
13	Land compensation	*	*	***	**	****
14	Land taxation	**	*	*	*	****
15	Road network management and development	*	*	**	**	****
16	Facility management	**	**	**	*	****
17	Forest production management	*	**	***	***	****
18	Forest/biodiversity conservation	**	***	***	****	****
19	Rapid Survey at Local level	**	***	**	****	****
20	Mining potentials and conservation	**	***	*	****	****

Survey summary: what kind of land-use information is needed?

It can be concluded that land-use information is recognised as an important theme within the KDLD. As the maps stored in the KDLD do not function properly due to various weaknesses, the land-use information should be prioritised for improvement and updating. However, other map themes also require improvement, particularly in terms of newness, accuracy and relevance. Moreover, there are at least two other themes should be added to support the land-use and other themes functioning, i.e. landform and DEM.

Furthermore, improvement in land-use information may be directed to the development of content comprising various aspects or dimensions, such as general and more detailed cover types, spatial, temporal and ecological dimensions, socio-economic function, as well as legal aspect. Therefore, the information completeness may satisfy various planning tasks that require a great diversity of LC and LU parameters and dimensions. However, it is also realised that the development of LU information, which should be versatile in character, will face the same problems if the remotely-sensed data and topographic map as the main source are rare or unavailable; and the mapping technology such as remote sensing, GIS and GPS are not mastered by the local staff. On the top of it, bureaucracy and budgeting in land-use mapping should also be considered, particularly in the area where changes in LC and LU take place very rapidly.

Versatile Land-use Classification Scheme

Findings in the previous stages were used as a significant input to the development of VLU classification scheme (Appendix). Specification and characteristics of various imagery currently available worldwide were also taken into consideration. The versatile LU classification scheme was then developed, characterised by the following:

1. Multidimensional , each dimension is associated with particular aspect of LC or LU
2. Multilevel, each level is associated with specific range of spatial resolution
3. Stored in a layer stack analogous to multiband in multispectral imagery, where each layer represent particular dimension/theme
4. Can be derived using remote sensing imagery and field data, supported by ancillary data stored in the KDLD.

In this versatile land-use classification scheme, a four level categorisation is set up. Level I is used for general characterisation of LC and LU over a large area, and should not practically be used for local planning. To say it in another way, this level only serves as a general guidance for subtler categories relevant to local planning. A spatial resolution of 100 m or coarser is suitable for this level.

Level II is designed for spatial resolution ranges from 30 to 100 m. At this level, categorisation of spectral dimension (expressed by cover types related to spectral responses) are at the same level with level II of the USGS LU and LC Classification System (Anderson *et al.*, 1976). However, it should be noted that some categories found in the USGS classification system may not be found here, since they may be categorised and grouped into different dimensions, *i.e.* spatial, temporal, ecological and socio-economic function.

Level III is designed for 5 – 30 m spatial resolution. At this level, subtler categories such as woody and non-woody vegetation with different densities may be distinguished. Lower spatial resolution may be compensated by higher spectral resolution, *e.g*. Landsat ETM+ with 30 m pixel size and 6 reflective bands is expected to perform similarly with SPOT-5 XS with 10 m pixel size and 4 reflective bands. Indeed, availability of multitemporal imagery also plays an important role, particularly to define the temporal and ecological dimensions. For remotely-sensed image with pixel size falling within categories transition, e.g. Landsat-7 ETM+ at 30 meter, effort may be made for mapping at level III, as far as the local knowledge and field data are fully supportive.

Level IV is the most detailed category requiring 0.5 – 5 m spatial resolution. This classification level is expected to be satisfied by new generation satellite imagery such as Ikonos or Orbview (1 m panchromatic and 4 m multispectral) and Quickbird (61 cm panchromatic and 2.4 m multispectral). Other airborne digital imagery with similar spatial resolution is expected to perform similarly.

It is also realised that with the advances of digital image and other spatial data processing, a subtler classification level may be achieved by using coarser spatial resolution imagery. The use of textural filters, buffer or distance model, hyperspectral analyses with linear unmixing or spectral angle mapper, fuzzy, artificial neural network as well as multisource classification methods may improve the classification details and accuracy. However, it is assumed that only the spectral dimension requires full spectral image classification, while the others may be approached, at least, using visual interpretation. A further study on the use of various digital mage processing techniques for classifying image with respect to this categorisation is being carried out (Phase II).

<u>Example for the First Dimension: Automatic Classification</u>

Since the large number of classes obtained from the spectral classification contains similar generic LC categories, a class merging operation needs to be run. During this stage, 40 spectral-related tentative cover classes from Landsat ETM+ image was merged to 27 land-cover classes with respect to the specified categories and spatial resolution under spectral dimension of the versatile LU classification scheme. By using the same procedure, 85 tentative classes obtained from multispectral classification were merged to 48 spectral dimension LC classes according to the versatile LU classification scheme. Figure 8 shows the result.

Accuracy assessment of the classified Landsat ETM+ and Quickbird images showed that the level of accuracy increases when the post-classification processes applied (Table 7). The immediate result of multispectral classification (original classified image) was less accurate as compared to the classified images of merged classes. Class merging consequently reduces the number of pixels of omission and commission. This particularly gives positive effect for tentative classes having relatively similar characteristics, e.g. shallow water_1 and shallow water_2 , which were then be merged into shallow water.

Table 7. Accuracy level of the classified images: original, merged, and majority-filtered classes.

Image data and number of bands	**Accuracy levels of classified data with respect to Versatile Land-use Classification Scheme**					
	Original classified image		**Merged classes**		**Global majority filtering**	**Selective majority filtering**
	Nr.of classes	**Accuracy Overall & Kappa***	**Nr.of classes**	**Accuracy Overall & Kappa***	**Accuracy Overall & Kappa***	**Accuracy Overall & Kappa***
Landsat-7 ETM+ (6 bands)	40	86.84 % (0.8628)	27	92.56 % (0.9211)	94.38% (0.9434)	94.13% (0.9378)
Quickbird (4 bands)	85	68.75 % (0.6813)	48	79.02 % (0.7829)	87.05% (0.8656)	85.90% (0.8539)

** The Kappa coefficients are put within brackets*

Statistically, however, global majority filtering gives a slightly better accuracy level than the selective one. The choice of field reference data and its digitisation in terms of ROIs has created solid areas with homogeneous label, matching the result of global majority filtering that can successfully remove minor variation within a given window. On the other hand, the use of selective majority filter that preserve particular classes with 1-2 pixels width has resulted a slightly heterogeneous features surrounding them. As a result, the omission and commission slightly increased and the overall accuracy slightly decreased as compared to the global majority filtered LC map.

Despite the higher overall accuracy levels and Kappa coefficients for global majority filtering result of both Landsat-7 ETM+ and Quickbird images, the selective majority filtering gives more reasonable result, particularly in preserving road and small river network, as well as clusters of settlement with clay roof tiles. The global majority filter tends to generalise these features so that they might be omitted from the scene.

The classification result also shows that Quickbird image with 2.4 m spatial resolution tend to give lower classification accuracy as compared to coarser spatial resolution such as Landsat-7 ETM+. It is parallel to the statement of Aplin *et al.* (1999) whose said that an increase in spatial resolution is associated with an increase in internal variability within land parcels ('noise' in the image), which may finally decrease the classification accuracy on a per-pixel basis. Moreover, the Quickbird image with 11-bit level of radiometric resolution (0-2048 grey level for each band) can show different spectral pattern for the same objects found in Landsat-7 ETM+ image.

Several works on high-spatial resolution imagery have proven that per-field classification (*e.g*. Aplin *et al*., 1999; Berberoglu *et al*., 2000) and textural or neighbourhood analyses within a given window (*e.g.* Jenkins and Phinn, 2002) might generate more accurate classification result than the 'traditional' per-pixel classification. Therefore, it is necessary to explore such methods for improving the classification result. However, this study also demonstrate that relatively subtler categorisation of cover types under the versatile LU classification scheme can be achieved through a careful sampling, classification and post-classification processes.

The Future Works (Phase II and III)

Once the versatile classification scheme is established, it requires further studies concentrating on the development of image analyses and classification methods for generating categories under other dimensions. Although it is obvious that all categories specified within the classification scheme can be mapped using visual interpretation, supported by adequate field data, automated mapping methods are still needed for more detailed and consistent information extraction. The availability of high-spatial resolution imagery such as Ikonos, Quickbird and Orbview should be in balance with the development of image analysis and information extraction methods.

To address this challenge, there are two sub-topics of research for the future works should be done:

a. Development of image classification and information extraction methods with respect to each category specified in the versatile LU classification scheme;
b. Demonstration of versatility of the developed VLUIS in various local planning tasks.

Research on the image classification and information extraction methods will be carried out in the Phase II. During this phase, methods and their mapping accuracies will be assessed in order to find the most appropriate and efficient image processing techniques for generating versatile LU information. The demonstration of the VLUIS versatility will be carried out by selecting several local planning tasks requiring LU information, e.g. industrial site selection, monitoring LU change, and soil loss prediction models.

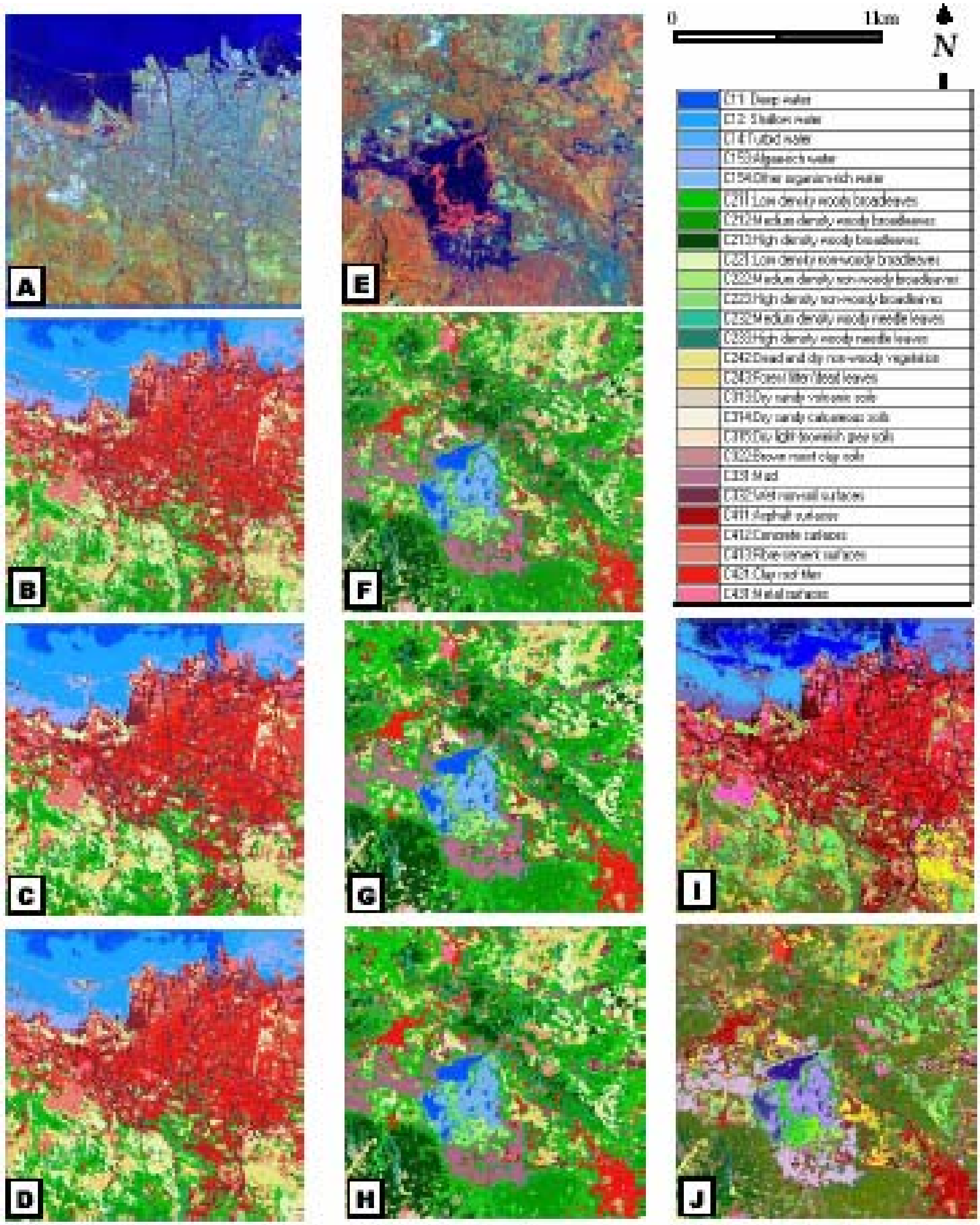

Figure 7. Landsat-7 ETM+ image classification result showed in small subsets. A and B are the colcour composite images representing urban and rural areas respectively, B and C are the immediate classification result with 40 classes, D and E are the merged classes (27), F and G are the selective majority-filtered images.

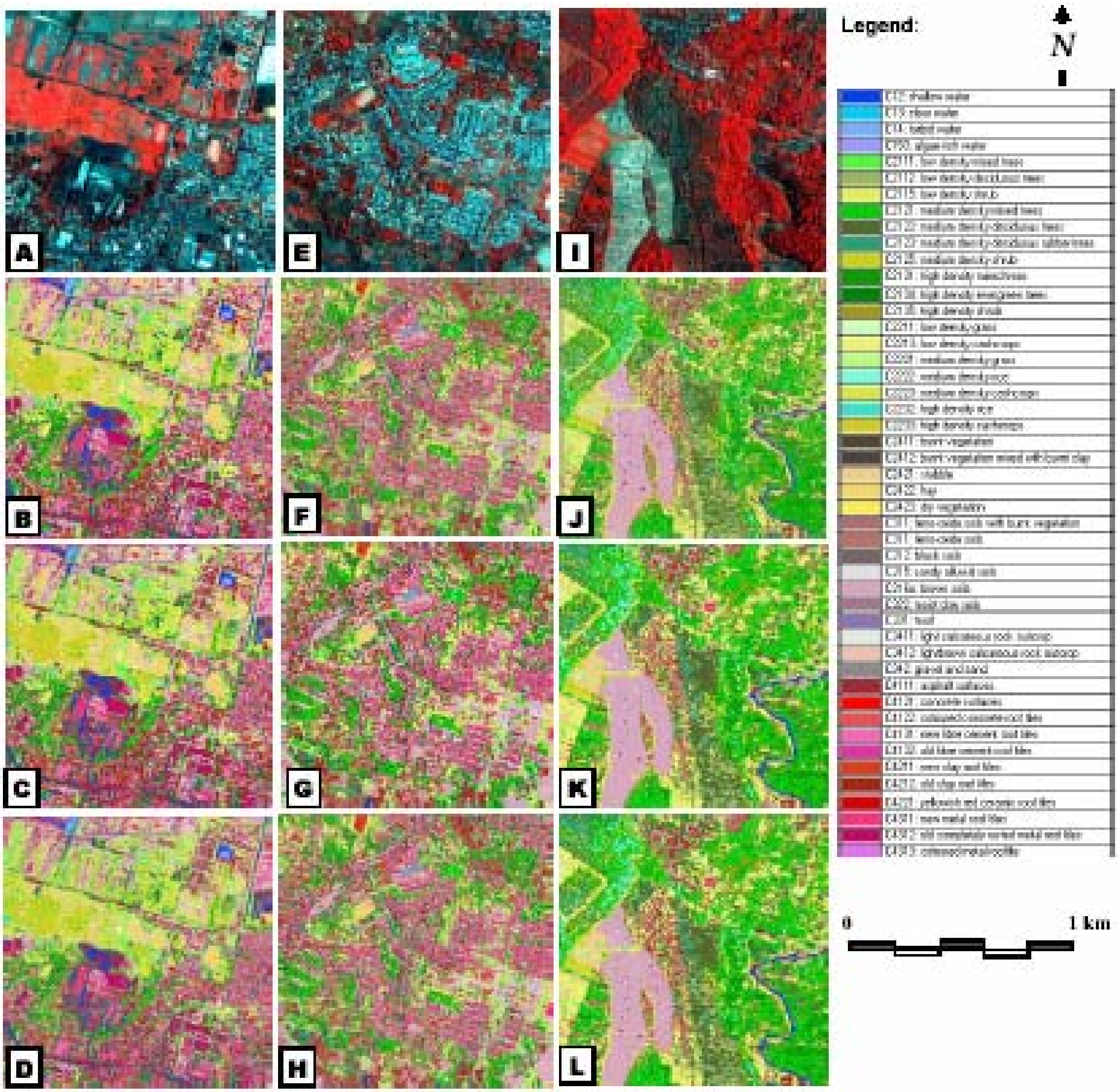

Figure 8. Quickbird image classification result showed in small subsets. A and B are the colour composite images representing urban and rural areas respectively, B and C are the immediate classification result with 85 classes, D and E are the merged classes (48), F and G are the selective majority-filtered images.

Concluding Remarks

During the past years, data availability and quality have become one of main interests in the development of GIS. Following this needs, model applicability and development are also required by various users. The development of VLUIS can be put in this context, by which the LU data are supplied and stored in such a way so that various models and applications may use it as a common reference for solving their own problems. From the local planning perspective, the availability of VLUIS should be put within the frame of KDLD, in which the improvement of LU information should also be undertaken together with other spatial data. Therefore, the applicability of the KDLD to support local planning tasks can be realised with the support of both LU and other relevant spatial data.

Landsat systems have been serving to provide data continuously during the past 30 years, and the data can be used as a good basis for monitoring system at both regional and local levels. This study has proven that the Landsat-7 ETM+ imagery is also accurate to be used as a basis for the VLUIS' first-dimension (LC type) mapping. However, further studies are required in order to ensure that this kind of imagery is also accurate for generating other VLUIS' dimensions.

It was also found that the Quickbird imagery, with its 2.4 meters spatial resolution, is accurate enough for satisfying LU mapping tasks with respect to the VLUIS' first dimension classification scheme. Although 85% accuracy level might be considered as 'marginally accurate', more complex analyses can still be developed in order to increase its accuracy, which will be carried out in the Phase II. It should also be noted that the processing methods applied to both Landsat-7 ETM+ and Quickbird imagery was a standard algorithm followed by a simple neighbourhood analysis technique, which can be done using most image processing systems available in the marketplace. Thus, the future works may also be expected to explore other methods for increasing the accuracy levels of the classification.

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Appendix

Proposed Versatile Land Use Classification Scheme (required spatial resolutions: level 1: >100m, II: 30-100m, IV: 0.5-5 m)

LAND USE DIMENSIONS

SPECTRAL-RELATED COVER (C)

C1 WATER BODIES
- C11 Deep water
- **C12 Shallow water**
- C13 Clear water
- **C14 Turbid water**
- C15 Organism-rich water
  - C151 Plankton-rich water
  - C152 Reef-rich water
  - C153 Algae-rich water
  - C154 Others

SPATIAL (S)

S1 WATER BODIES
- S11 Sea (no further details/level 4)
  - S111 Open sea
  - S112 Bay
  - S113 Strait

S12 Lake
- S121 Inland lake
  - S1211 Oxbow lake
  - S1212 Others
- S122 Atoll/lagoon
  - *No further details (level 4)*

S13 River and channel
- S131 River
  - *No further details (level 4)*
- S132 Rivulet and channel
  - S1321 irrigation
  - S1322 drainage
  - S1323 irrigation and drainage

S14 Pond (no further details/level 4)
- S141 Coastal pond
- S142 Inland pond

S15 Others

TEMPORAL (T)

T1 LENGTH OF INUNDATION-RELATED FEATURES

T11 Permanently inundated

T12 Periodically or seasonally inundated
- T121 Tidal areas
- T122 Flooded areas
- T123 Inundated fields

T13 Temporarily inundated
- T131 Unusual flood area
- T132 Others

T14 Non-inundated area

ECOLOGICAL (E)

E1 AQUATIC ENVIRONMENT

E11 Deep seawater environment

E12 Littoral aquatic environment
- E121 Littoral environment with coral floor
  - E1211 *Littoral environment with coral sand*
  - E1212 *Littoral environment with coral reefs*
- E122 Littoral environment non-coral floor
  - E1221 *Littoral environment with non-coral rocks floor*
  - E1222 *Littoral environment with volcanic sands*
  - E1223 *Littoral environment with mud floor*

E13 Semi-closed aquatic environment
- E131 Lagoon
- E132 Others

E14 Lake and pond
- E141 Natural lake
  - E1411 *Volcanic lake*
  - E1412 *Atoll*
  - E1413 *Non-volcanic freshwater lake*
- E142 Man made lake and pond
  - E1421 *Man-made lake*
  - E1422 *Man-made pond*

SOCIO-ECONOMIC FUNCTION (F)

F1 WATER-BASED UTILISATION

F11 Reservoir

F12 Aquaculture
- F121 freshwater fish rearing
  - F1211 freshwater fishpond
  - F1212 other freshwater fish rearing (e.g. karamba)
- F122 brackish and salt water aquaculture
  - F1221 shrimp pond
  - F1222 coastal fishpond
  - F1223 salt pond
  - F1224 Sea grass

F13 Fishing and recreational water bodies
- F131 Fishing ground
- F132 Recreational water body

F14 Waterway and harbour
- F141 Waterway
- F142 Harbour

F15 Multipurpose use

C2 VEGETATION COVER

C21 Woody broadleaves

C211 Low-density woody broad leaves
C2111-C211n *Crop types*
C212 Medium-density woody broad-leaves
C2121-C212n *Crop types*
C213 High-density woody broad- leaves
C2131-C213n *Crop types*
C22 Non-woody broadleaves
C221 Low-density non-woody broad leaves
C2211-C221n *Crop types*
C222 Medium-density non-woody broad leaves
C2221-C222n *Crop types*
C223 High-density non-woody broad leaves
C2231-C223n *Crop types*

C23 Needle leaves

C231 Low density needle leaves
C2311-C231n *Crop types*
C232 Medium density needle leaves
C2321-C232n *Crop types*

C232 High density needle leaves
C2331-C233n *Crop types*
C24 Burned, dead and dry vegetation
C241 Burned vegetation
No further details
C242 Dead and dry vegetation
C2421 Stubble
C2422 Hay
C2423 Dry vegetation

S2 VEGETATION STRUCTURE & COMPOSITION

S21 Homogeneous stands
S211 Regularly-spaced stands
No further details (level 4)
S212 Irregularly-spaced stands
No further details (level 4)
S22 Heterogeneous stands
S221 Regularly spaced, heterogeneous
S2211 *Interleave planting*
S2212 *Others*
S222 Mixed forest
No further details (level 4)
S223 Mixed bushy woodland
No further details (level 4)
S25 Forest mosaic
No further details (level 3 & 4)
S24 Shrub *(no further details/level 4)*
S221 Mix of shrub and grass
S222 Shrub mosaic
S23 Herbaceous vegetation and grass
S231 Homogeneous herbaceous vegetation and grass
S2311 *Regularly spaced herbaceous vegetation*
S2312 *Irregularly spaced herbaceous vegetation*
S232 Heterogeneous herbaceous vegetation and grass
S2321 *Interleave planting*
S2322 *Others*
S233 Herbaceous mosaic with field blocks
No further details (level 4)

T2 VEGETATION CHANGE-RELATED FEATURES

T21 Relatively stable/ no change in vegetation cover
T211 No change
T212 Evergreen vegetation
T22 Seasonal changes in vegetation cover
T221 Periodical treatment
T2211 Pruning
T2212 Stand density reduction
T222 Deciduous

T24 Growing vegetation

T241 Greening
T242 Senescent
T243 Regrowth
T244 Seed growing

T25 Rotation planting

T251 Continuous planting
T2511 planting with the same crop(s)
T2512 rotation with different crop(s)
T252 Interrupted planting
T2521 cropping period
T2522 fallow period with weeds
T27 Others

T4 OPEN SOILS CHANGE-RELATED FEATURES

T41 Unchanged open soils (no further details for level 3 and 4)

T42 Rotation planting-related soil features (no further details for level 4)

T421 Fallow period (no vegetation cover)

T422 Soil tillage/ploughing period

E2 WETLAND and RIVERSIDE ENVIRONMENT

E21 Freshwater wetland

E211 Floating vegetation
E2111-E211n *Vegetation types(e.g. Eichhornia crassipes)*
E212 Herbaceous swamp
E2121-E212n *Vegetation types(ecofloristic composition)*
E213 Swamp forest
E2131-E213n *Vegetation types (echofloristic composition)*
E22 Coastal&estuarine environment

E221 Non-vegetated tidal mudflat
E222 Mangrove formation
E2221 *Avicennia zone*
E2222 *Rhizopora zone*
E2223 *Bruguiera zone*
E2224 *Others*
E223 Non-mangrove coastal vegetation

E3. LOWLAND AND ALLUVIAL LAND ENVIRONMENT

E31 Lowland, non-alluvial environment
E311 Lowland evergreen vegetation
E312 Lowland deciduous vegetation
E313 Lowland savannah environment
E314 Lowland herbaceous vegetation and open fields

E32 Alluvial land environment

E321 Flood plain vegetation and open fields

E322 Terrace, fans and other alluvial plain vegetation and open fields

F2 FOREST-BASED UTILISATION

F21 Conservation and recreational forest
F211 Conservation forest
F212 Recreational forest
F213 Conservation and recreational forest

F22 Production forest

F221 Teak forest
F222 Mahogany forest
F223 *A. auriculiformis* forest
F224 *D. latifolia* forest
F225 *P. mercusii* forest
F226 Albizia forest
F227 Others
F23 Reserve and confined production forest
F231 Reserve forest
F232 Confined production forest

C3 BARREN LAND/OPEN SOILS

C31 Bare soil, dry
- C311 Ferro-oxide soils
- C312 Black, calcareous soils
- C313 Sandy, volcanic soils
- C314 Sandy, calcareous soils
- C315 Others..

C32 Bare soil, moist
- C321 Humic-rich/organic soils
- C322 Other moist soils

C33 Mud and Wet surface
- C321 Mud
- C322 Wet non-soil surface

C34 Rock outcrop
- C341 Light-tone outcrop
- C342 Dark-tone outcrop
- C343 Others

C4 PAVED/IMPERVIOUS SURCAFE

C41 Asphalt, concrete and cemented surface
- C411 Asphalt surface
- C412 Concrete surface
- C413 Fibre-cement surface

C42 Compacted clay surface
- C421 Clay roof tile
- C422 ceramic roof tile
- C423 Others

C43 Metal, glass, fibreglass and plastic surface
- C431 Metal surface
- C432 Glass surface
- C433 Fibreglass and plastic surface
  - C4331 Fibreglass surface
  - C4332 Plastic surface

C44 Others

S3 BARREN LAND/OPEN SOILS

S31 Coastal barren land
- S311 Coastal sandy surface
  - S3111 *Coastal volcanic sand*
  - S3112 *Coastal coral sand*
  - S3113 *Others*
- S312 Coastal mudflat
  - *No further details (level 4)*
- S313 Coastal rocky surface
  - S3131 *Coastal coral rocks*
  - S3132 *Others*
- S314 Others

S32 Fluvial barren land (no further details/level 4)
- S321 Riverside sandy area
- S322 Sandbar

S33 Volcanic barren land (no further details/level 4)
- S331 lahar field
- S332 lava field
- S333 Others

S34 Others

S4 BUILT-UP / PAVED SURCAFE

S41 Homogeneous built up features
- S411 Sparse homogeneous built-up features
- S412 Dense homogeneous built-up features

S42 Heterogeneous built-up features
- S421 Regular built-up features
- S422 Irregular built-up features

S43 Linear built-up/paved surface
- S431 Paved road network
- S432 Unpaved road network

S44 Specifically shaped built-up/paved surface

T4 DEVELOPMENT STAGE-RELATED FEATURES

T41 Old built up areas (no further details for level 3 & 4)

T42 New built up areas (no further details for level 3 & 4)

E4 MONTANE AND STEEPER LANDS ENVIRONMENT

E41 Lower montane environment
- E411 Lower montane rainforest
- E412 Lower montane shrub and herbaceous vegetation
- E413 Lower montane open fields

E42 Upper montane environment
- E421 Upper montane rainforest
- E422 Upper montane shrub and herbaceous vegetation
- E423 Upper montane open fields

E43 Non-montane steeper land environment
- E431 Forest and woodland on steeper lands
- E432 Shrubs, herbaceous vegetation on steeper lands

E433 Grassland and open fields on steeper lands

F3 AGRICULTURAL USE

F31 Pasture land
- F311 Extensive grazing
- F312 Confined grazing

F32 Tree crop plantation/estate
- F321 Tea plantation
- F322 Rubber plantation
- F323 Coffee plantation
- F324 Cocoa plantation
- F325 Coconut plantation
- F326 Oil palm plantation
- F327 Clove plantation
- F327 Others

F33 Non-woody plantation/estate
- F331 Sugarcane
- F332 Tobacco
- F333 Shallot/Garlic
- F334 Vanilla
- F335 Others

F34 Inundated Rice field (sawahs)
- F341 Continuous ricefield
  - F3411 Rice 2x
  - F3412 Rice 3x
- F342 Rice 2x and cahscrop
  - F3421 Rice 2x + single cashcrop
  - F422 Rice 2x +multiple cashcrop
- F343 Rice 1x and cashcrop
  - F3431 Rice 1x + single cashcrop
  - F3432 Rice 1x + multiple cashcrop
- F344 Rice 2x and vegetables
- F345 Rice 1x and vegetables
- F346 Rice and fish rearing

F35 Dry land cultivation
- F351 Rainfed ricefield
- F352 Dryfield with cashcrops
- F353 Dryfield with vegetables

F36 Agroforestry systems
- F361 Homestead garden
- F362 Mixgarden
- F363 Orchards
- F364 Forest garden
- F365 Others