Multi-scale GIS based Satellite Image Mapping

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Abstract. Remotely sensed imagery has an enhanced capability of extracting information about small image structures (both artificial and natural objects). Fast, low cost, accurate and spatially rich data can be acquired via remote sensing technology. For this reason, satellite image mapping is quite common technique and image maps provide a great contribution to cartography and Geographic Information Systems as data sources. However, there are several remote sensing satellites with various kinds of spectral and spatial resolution and they detect different regions of electromagnetic spectrum. One needs to know which satellite image is suitable for which kind of mapping. On the other hand, image mapping which is based on resolution is a procedure including information extraction from pixels. While pixel algorithms and processing methods are suitable for medium and low resolution images, pattern recognition is suitable for high resolution images. Thus, there is a need to evaluate maps according to scale and satellites according to resolution level and see if they are matching or not.

This paper aims to examine the possibilities of map production by using remote sensing imagery, to set out representation criteria for map features and to discuss the results by means of efficiency, accuracy, consistency and usability. In this context, first of all, the map concept was examined in terms of scale and content of the map. A requirement matrix was produced in order to execute the requirement analysis on the content of each map type based on the scale. Secondly, remote sensing images, having different spatial and spectral characteristics, were examined in a similar approach and a requirement matrix was formed for determining the data extraction level of remote sensing imagery based on spatial and spectral characteristics. Finally, these two matrices were evaluated in order to assess the use of the remote sensing images in terms of mapping.

Keywords: Satellite image mapping, requirement matrix, scale, resolution

1. Introduction

With the development of the remote sensing satellite capabilities, a term called “image map” has become popular and it is certain that image maps provide great contribution to cartography. Image data contains numerous information which can be used in any up-to-date facts about landscape status and changes. They can also be used as a base map for thematic mapping approaches. Thus, a satellite image map can be described as a satellite imagery in a map sheet format representing two major types of geographical information (raster data and vector data of related features) (Albertz et al., 1992; Sunar et al., 2006). However, there are some considerations while using remote sensing data such as defining time, spectral and spatial resolution depending on individual purposes and land segmentation in order to determine a specific resolution.

It is crucial to define which remote sensing imagery should be used in which kind of mapping considering resolution and scale relationship. For that reason, desired content of the map should be determined depending on the map type. This paper is mostly a review of information based on satellite image mapping which aims to create a list/database of map content elements for different map scales and investigate the existence of them on corresponding image maps.

In the context of the study, first of all, the map concept should be introduced. According to ICA’s definition (2006) a map is a “symbolised image of geographical reality, representing selected features or characteristics, resulting from the creative effort of its author's execution of choices, and is designed for use when spatial relationships are of primary relevance”. Maps are also scaled representations of real word objects. There are three main map classification by scale; small scaled (≤ 1 : 1 000 000), medium scaled (1 : 25 000 – 1 : 300 000) and large scaled (≥ 1 : 10 000) (Spiess, et al., 2002). Maps are also divided into two categories as thematic and topographic based on content. Topographic maps are considered as cases with in the content of this study because, it was more convenient to match national and international mapping standards in terms of topographic map contents. Topographic maps are produced between the scales of 1 : 5 000 and 1 : 1 000 000.

Secondly, remote sensing imagery is needed to be classified because there are several remote sensing satellites having different spectral and spatial characteristics; some can be used for cartographic purposes and some can not. Both spatial and spectral characteristics are important for cartographic mapping. Spectral characteristics may be much more necessary for thematic mapping purposes. However when topographic mapping considered, it will be enough to look at spatial characteristics of satellites. Based on spatial resolution, remote sensing imagery can be classified as very high (≤ 2,5 m), high (2,5 m - 10 m), medium (10 m - 100 m) and low (≥ 100 m) resolution.

2. Methodology

The main consideration of the study is to introduce and organize the information themes that each map has to show. Frye (2006) states that organization creates its map a profound impact on the quality and utility of any publicly disseminated information that will come from that map. In the first step, organization of information themes (map content elements) was carried out by reviewing different published and unpublished national and international standards such as;

- "Cartographic Vector and Digital Map Details and Special Symbol Direction of General Command of Mapping" (GCM, 2002),
- Swiss Federal Office of Topography (Swiss Topo) topographic map production standards (Spiess et al., 2002),
- "Land Cover Classification System for the Use of Remote Sensing Data" of United States Geological Survey (USGS) (Anderson, 1976),
- Corine land-cover classification standards (Bossard et al., 2000),
- Institut Géographique National (IGN France) example printed maps.

After gathering all the information from above sources, (for detailed information; the sources above were given in the references) four main information themes were determined. Transportation, vegetation, administrative and hydrographic themes were handled as different level of details (sub-classes). While choosing names for information themes, it has been aimed that these names should be general names accepted by various authorities and able to cover all the land structures that can be subjects of a topographic map.

Second step was to list the contextual information that each map scale needs to cover its purpose. Themes and sub-classes of each theme were examined based on different map scales. Geometric characteristics of each sub-classes were also determined here. For instance; administrative theme has "boundary" sub-class and "boundary sub-class has "national boundary' sub-class. At 1 : 5 000 scale, national boundaries are shown and geometric characteristic of this object is defined as polyline (Table 1). Afterwards, these themes and sub-classes and object characteristics of sub-classes were integrated to create requirement matrices for maps.

			1 : 5 000	1 : 10 000	1 : 25 000
Administrative	Boundaries	National Boundaries	polyline	polyline	polyline
		Province Boundaries	polyline	polyline	polyline

Table 1. Example contextual information about “administration” information theme.

Another consideration is limiting resolution, i.e., the size of the smallest object that can be shown legibly on a map. This is usually assumed to be approximately 0.15mm and is often called the zero dimension [Url 1]. Smallest detail at cartographic representation was determined in order to identify the representation limits of each scale. This statement can be formulated as follows (Equation 1):

$$\text{mobject} = +/-[\,(0.15\ M) / 1000]\ (m) \qquad (1)$$

Here m represents the error, M is the scale factor and dividing by 1000 is from unit transformation. This means that smallest detail that 1 : 5 000 scaled topographic can show is 1,5m.

Third step was to investigate the (above mentioned) contextual information that each remote sensing imagery having different spatial resolution to fulfill its purpose. Thus, scale and spatial resolution relationship was tried to be formed. For the information contents based on experience there is the rule of thumb of 0.05 up to 0.1mm Ground Sampling Distance (GSD) in the representation scale (Doyle 1984). This statement is formulated below (2):

$$\text{Resolution} = \text{Scale} * \text{GSD} \qquad (2)$$

Thus to generate 1 : 10 000 scale map, 0.5 – 1 m GSD image is needed (0.05m * 10 000 = 0.5m or 0.1m * 10 000 = 1m). Based on this formula resolution-scale relationship were calculated (Table 2). The approximate values presented in Table 2 were used to create a requirement matrix for remotely sensed data.

SCALE	RESOLUTION (m)
1 : 5 000	0.25 - 0.5
1 : 10 000	0.5- 1
1 : 25 000	1.25 - 2,5
1 : 50 000	2,5 - 5
1 : 100 000	5 - 10
1 : 200 000	10 - 20
1 : 500 000	25 - 50
1: 1 000 000	50 - 100

Table 2.: Map Scale and Satellite Image Resolution Relationship.

Based on Table 2, requirements for each spatial resolution was tried to be specified. Here, each sub-class was determined based on its existence. For instance, residential buildings need to be extracted from 0,5 m resolution imagery, thus there is a (+) at its cell value (Table 3).

<table>
<tr><td></td><td></td><td></td><td colspan="3">Very High Resolution (≤2,5 m)</td></tr>
<tr><td></td><td></td><td></td><td>0,5 m</td><td>1 m</td><td>2,5 m</td></tr>
<tr><td>Administrative</td><td>Settle-ment</td><td>Residen-tial</td><td>(+)</td><td>(+)</td><td>(+)</td></tr>
<tr><td></td><td></td><td>Commer-cial and Services</td><td>(+)</td><td>(+)</td><td>(+)</td></tr>
</table>

Table 3.: Example contextual information about “administration” information theme.

Additionally, small application was conducted to illustrate the theoretical information mentioned above. A plot area, approximately 20.000 m2, was chosen to extract administrative features. The data of the study consists of three different satellite images (i)September 2011 dated Worldview-2 image, (ii)August 2011 dated Spot-5 pan sharpened image and (iii)August 2011 dated Landsat-5 TM image which are having 50 cm, 2,5 m. and 30 m. spatial resolution respectively. After preparing specifying the administrative area from all three satellite images, building features were digitized by using ArcMap software and results were compared.

3. Results

Information theme called “administrative” was chosen as an example and as a result, a requirement matrix for maps were created based on the scale from 1 : 5 000 to 1 : 1 000 000 (Attachment 1). The requirement matrix was formed mostly based on Swiss Society of Cartography information themes. However some sub-classes were specified according to published standards General Command of Mapping (GCM) in Turkey (i.e. town and village boundaries were added to the matrix for that matter). At the very last row of the requirement matrix, there is representation characteristics for building features. These values were calculated for each scale with the formula given in the Equation 2 (Table 4):

Smallest detail (m)	Scale
+/- 0.75	1 : 5 000
+/- 1.5	1 : 10 000
+/- 3.75	1 : 25 000
+/- 7.5	1 : 50 000
+/- 15	1 : 100 000
+/- 30	1 : 200 000
+/- 75	1 : 500 000
+/- 150	1 : 1 000 000

Table 4. Smallest detail at cartographic representation.

In a similar approach (implemented for maps), a requirement matrix for remotely sensed data was also prepared based on spatial resolution (Attachment 2). This requirement matrix was formed based on the information themes determined for maps. Each cell in that matrix was filled considering the theoretical values calculated in Table 2. Cell values get (-) or (+) according to extraction characteristics of satellite data. Besides showing information about different level of details, requirement matrices give also information about representation of the sub-classes. For instance buildings are presented individually at 1 : 25 000 scale whereas they are merged starting from the scale of 1 : 25 000. Again according to the Attachment 2, individual buildings should be extracted with very high resolution satellites.

Following figure shows the comparison of different satellite images belonging to the same study area (Figure 1). It is obvious that high resolution imagery (Worldview-2) can show all the necessary details to extract information about settlement whereas the low spatial resolution imagery (Landsat-5 TM) can represent the same area with only few pixels. It is impossible to receive any thematic information about the feature seen on the image. Thus, for building identification at least 2,5 m is required. But for the complete thematic information, better resolution is needed. Worldview-2 which has 0.50 m spatial resolution substitutes the requirement matrices.

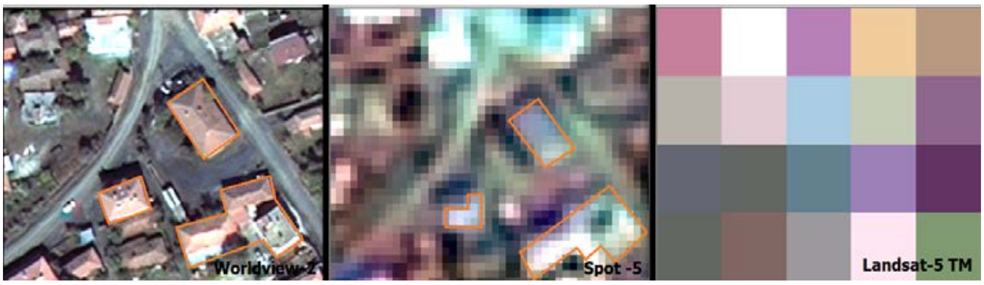

Figure 1. Worldview-2, Spot-5 and Landsat-5 TM images belonging to the administrative area.

4. Conclusion and Discussion

When compared two requirement matrices (Attachment 1 and 2), abstract map object problem occurred. Abstract objects like boundaries, city centers or etc. are not real world objects, thus they cannot be extracted from imagery. If they are needed to be mapped, some additional land information is required.

Achieving the expected thematic and geometric accuracy is not easy to achieve in practice. Satellite images may not meet the required accuracies determined theoretically. As seen in Figure 1, Landsat-5 TM image failed to determine even the general characteristics of the residential area. However based on the requirement matrix in Table 6, from medium resolution satellites it is possible to extract the residential areas. This lack of information may have several reasons such as temporal and spectral resolution, surface or object reflectance, sun elevation and etc. To extract thematic information from satellite image data, experience is high required. There should be a spectral library for land objects and field works should be conducted. Plus, visual interpretation is very important for object identification.

To form a direct relationship between scale and spatial resolution may not be correct. Because only spatial resolution parameter is not enough to interpret a remote sensing data in order to produce maps at relevant scale.

For further research, quality assessment by means of both thematic and geometric accuracy should be conducted to assess the credibility of the work. This study can be extended to an MRDB (Multi-Representation Database) system to store and display the same real world objects at different levels of accuracy and resolution.

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Url-1 <http://www.cise.ufl.edu/~mssz/GIS/GIS-Basics.html>

Attachment 1. Requirement Matrix for the Administrative Content

			1 : 5 000	1 : 10 000	1 : 25 000	1 : 50 000	1 : 100 000	1 : 200 000	1 : 500 000	1 : 1 000 000
Administrative	***Boundaries***	*National Boundaries*	polyline	polyline	polyline	polyline	polyline	polyline	polyline	polyline
		Province Boundaries	polyline	polyline	polyline	polyline	polyline	polyline	polyline	polyline
		Municipal Boundaries	polyline	polyline	polyline	polyline	polyline	polyline	polyline	polyline
		Town Boundaries	polyline	polyline	polyline	polyline	polyline	polyline	polyline	polyline
		Village Boundaries	polyline	polyline	polyline	polyline	polyline	polyline	polyline	polyline
		District Boundaries	polyline	polyline	polyline	polyline	polyline	polyline	polyline	polyline
	Settlement	*Residential*	polygon	polygon	polygon	polygon	polygon	polygon	point	point
		Commercial and Services	polygon	polygon	polygon	polygon	polygon	polygon	point	point
		Industrial	polygon	polygon	polygon	polygon	polygon	polygon	point	point
Representation	***Buildings***	*Urban Buildings*	individual buildings	individual buildings (simplification)	important buildings shown individually close buildings are merged (elimination, exaggeration, displacement)	buildings are merged (aggregation - geometrically)	buildings are merged (aggregation - geometrically)	buildings are merged (aggregation - geometrically)	point-based representation (based on population)	point-based representation (based on population)

LEGEND

- smallest detail is 1,5 m.
- smallest detail is 3 m.
- smallest detail is 7,5 m.
- smallest detail is 15 m.
- smallest detail is 30 m.
- smallest detail is 60 m.
- smallest detail is 150 m.
- smallest detail is 300 m.

Attachment 2. Requirement Matrix for the Administrative Content

			Very High Resolution (≤2,5 m)			High Resolution (2,5 m - 10 m)		Medium Resolution (10 m - 100 m)		Low Resolution (≥ 100 m)
			0,5 m	**1 m**	**2,5 m**	**5 m**	**10 m**	**20 m**	**50 m**	**100 m**
Administrative	***Boundaries***	*National Boundaries*	*Abstract Objects (-)*							
		Province Boundaries								
		Municipal Boundaries								
		Town Boundaries								
		Village Boundaries								
		District Boundaries								
	Settlement	*Residential*	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
		Commercial and Services	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
		Industrial	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
Representation	***Buildings***	*Urban Buildings*	individual buildings	individual buildings	some of individual buildings	detection of building blocks	detection of building blocks	residential/ administrative area	poor detection	poor or no detection

*Boundaries are abstract map elements, thus they are not detected by using remotely sensed data.