URBAN LAND COVER CHANGE ANALYSIS: THE VALUE OF COMPARING HISTORICAL SPY PHOTOS WITH CONTEMPORARY DIGITAL IMAGERY

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ABSTRACT:

Declassification of high-resolution intelligence satellite photos from the Corona and Gambit programs (KH-1 through KH-4B and KH-7) has provided more than 879,000 scenes of the land surface acquired between 1960 and 1972. The spatial resolutions of these photographs are nominally comparable to current high-resolution commercial satellite imagery (*e.g.*, IKONOS, QuickBird). Public access to this historical image record enables investigation into urban land cover change. However, the declassified imagery suffers from multiple limitations, including variable ranges in tone and contrast, geometric distortions, and sparse image metadata. How can these data be used to characterize urban land cover change in conjunction with current sensors? Within the context of a NASA LCLUC project on Kazakhstan, we acquired QuickBird imagery for the city of Almaty (2002/09/08) from DigitalGlobe, Inc. Corona and Gambit images of Almaty were acquired from the USGS archives. Two Gambit images (1964/04/23 and 1966/01/27) and two Corona images (1968/08/13 and 1971/09/17) were found for Almaty. The photos were acquired as film diapositives suitable for high-resolution scanning. For comparison purposes, a pseudo-albedo band was generated from the QuickBird data and the declassified photos were then co-registered to the QuickBird imagery. Observed types of urban change included expansion, densification, landscape transformation, and afforestation. Roads and individual buildings were also distinguishable. These results indicate that the historical satellite datasets can provide valuable information for the study of urban land cover dynamics.

1. INTRODUCTION

Declassification of high-resolution intelligence satellite photos from the Corona and Gambit programs (KH-1 through KH-4B and KH-7) has provided more than 879,000 scenes of the land surface acquired between 1960 and 1972 (USGS, 2003). This imagery provides an important window into the past and can serve as a valuable tool for land cover/land use change (LCLUC) research. Corona KH-4B and Gambit KH-7 satellite photographs offer a temporal range and spatial resolution previously unavailable to the public. The spatial resolutions of historic KH-4B and KH-7 photographs are nominally comparable to current very high spatial resolution imagery available from commercial spaceborne sensors. This high spatial resolution is appropriate for urban land cover studies and enables the characterization and quantification of urban features and their change.

Coarser spatial resolution declassified satellite photographs have been used successfully to study changes in the Greenland ice sheet (Zhou and Jezek, 2002). These studies covered a large extent and utilized ARGON (KH-5 @ 140 m) data with a 1992 ERS Synthetic Aperture Radar mosaic. Applications of declassified intelligence satellite photographs, such as Corona and Gambit, to urban areas present different challenges because of the heterogeneity and dynamism of urban and peri-urban environments. It is critical to develop a better understanding of this image data set in order to analyze it effectively. However, the declassified imagery suffers from multiple limitations, including variable dynamic ranges, geometric distortions, and sparse image metadata.

2. STUDY AREA

Almaty is located approximately 43° 15' 00" N, 76° 57' 00" E. Almaty was the capital of Kazakhstan from 1927 until 1997. It is Kazakhstan's largest city with a population of over 1 million and rests at the base of the Ala-Tau Mountains at an elevation of 700-900 m. Almaty is characterized by tree lined boulevards, parks, fountains, and gardens and is considered Kazakhstan's economic and cultural center (Analysis and Strategic Research Center, 2003). Between 1939 and 1959, the population of Almaty rose from 221,600 to 456,000 (Lahmeyer, 2003). The influx of people resulted in a housing shortage and led to the development of large residential complexes during the 1960s (Medvedkov, 1990). Between 1959 and 1973, the population of Almaty further rose from 456,000 to 794,000 (Lahmeyer, 2003). In 1991, Kazakhstan gained independence after the collapse of the Soviet Union. This resulted in dramatic political, economic, and environmental changes for Kazakhstan (de Beurs and Henebry, 2004). Almaty witnessed substantial growth in industry and tourism. Many large hotels have recently been built and various international events are held here due to the well developed infrastructure (Analysis and Strategic Research Center, 2003).

3. METHODOLOGY

QuickBird multispectral data were acquired for Almaty from 2002/09/08 through the NASA Scientific Data Purchase program. The data arrived from DigitalGlobe, Inc. as level 1b radiometrically corrected GeoTIFF files on DVD. The spatial resolution is 2.94 meters x 2.69 meters and the areal extent of the imagery is approximately 350 km^2. The northern part of Almaty was cut off in the QuickBird imagery. The imagery was converted to radiance and geometrically rectified to UTM zone 43 North using WGS-84 datum. For comparison purposes, a pseudo-albedo band was generated from the QuickBird multispectral data by summing together the blue, green, red, and near-IR bands.

The USGS archives were searched in order to assemble as temporally dense a time series as logistically feasible. Corona

KH-4B photographs were found from 1971/09/17 and 1968/08/13. Because the city extended over the edge of the photographs, two photos for each date were acquired, encompassing a northern and southern section of Almaty. Two Gambit KH-7 photographs were also acquired for Almaty from 1966/04/27 and 1964/01/23.

Declassified intelligence satellite photos are available from the USGS in paper print, film negative, and film positive formats. The Corona film was scanned at 16 μm (1600 dpi) using a flatbed scanner. The resulting image files were manually co-registered to the QuickBird multispectral imagery. For Almaty, 130 and 111 GCP were selected for the 1964 and 1966 Gambit photographs. RMS errors of 5.56 and 4.86 were achieved using a 4th degree polynomial. For the 1968 photos, 91 and 89 GCP were selected resulting in RMS errors of 3.53 and 8.51 using a 2nd degree polynomial. For the 1971 imagery, 77 and 50 GCP were selected and RMS errors of 0.89 and 0.88 were achieved using a 2nd degree polynomial. The RMS errors were due to differing sun/target/satellite geometries and differing spatial resolutions of the imagery, but were adequate for image-to-image comparisons. Image mosaics were generated from the 1971 and 1968 imagery. This resulted in a seam that is evident across the image due to uncontrolled radiometric differences. Some urban features did not align correctly due to co-registration errors.

Changes between the imagery were determined through visual interpretation. Visual interpretation elements such as location, size, shape, shadow, tone, texture, and pattern were used. Subsets of the imagery were generated within and near the city where changes were evident. Noticeable changes in land cover between the imagery were manually digitised and imported into a GIS.

4. RESULTS & DISCUSSION

Figure 1 is a subset of the declassified photos, just outside downtown Almaty. Total image area is 3.8 km^2. The time-series imagery demonstrate the 'densification' of the area, the transition of small sized buildings/houses to larger sized buildings/apartments (due to space limitations the 1971 photo is not shown). In the 1964 and 1966 photos, roads and buildings are clearly visible. Large, elongated building complexes, typical of Soviet architecture, are visible near the edges. The 2002 image shows that the high density residential (HDR) complexes encompass nearly the entire image and that roads and buildings are partially covered from fully grown trees. The areas of the HDR areas were manually digitised for each image. The data was imported into a GIS where changes could be visualized. The results in table 1 reflect the rapid increase in population during the 1950s – 1970s in Almaty. Housing shortages were alleviated by the building of large, rectangular residential complexes.

Year	1964	1966	1968	1971	2002
HDR area (m^2)	650	680	770	880	1980
HDR as % of total area	17.1	17.9	20.3	23.2	52.1
% change in HDR area	n/a	4.6	13.2	14.3	125.0

Table 1. Digitised results from high density residential (HDR) subset of Almaty. Total area of subset is 3.8 km^2.

The Corona and Gambit photographs provide a spatial resolution and temporal range previously unavailable. The photos act as windows into the past. Their use in conjunction with QuickBird data demonstrates the potential of declassified intelligence satellite photographs to characterize urban land cover dynamics. Types of observed urban land cover change include urban densification, urban expansion, afforestation, and landscape transformation. Declassified intelligence photos can provide accurate comparisons of land cover for a specific area and act as a baseline when used with current imagery. The total areal extent of the Corona archive is at approximately 1.1 – 1.4 billion km^2 (McDonald, 1995) with the majority of the imagery emphasizing Eastern Europe and Asia (USGS, 2003).

Challenges exist with the use of these data. Identifying and characterizing land cover changes using visual interpretation methods are tedious and time consuming. Visual interpretation methods rely on the investigator and can result in misinterpretation. Variability in the sun/target/sensor geometry of the declassified photographs proved problematic and produced errors in the image co-registration. QuickBird imagery also is usually acquired off-nadir and there is little control to acquire a specific area at a specific time of year or day. Shadows in high spatial resolution imagery can pose problems for analysis and interpretation. The view angle of the satellite and shadows, due to buildings and trees, can cover the land surface and obstruct visual interpretation; at the same time, shadows can aid image interpretation by offering cues about the three dimensional structure of the surface.

5. ACKNOWLEDGMENTS

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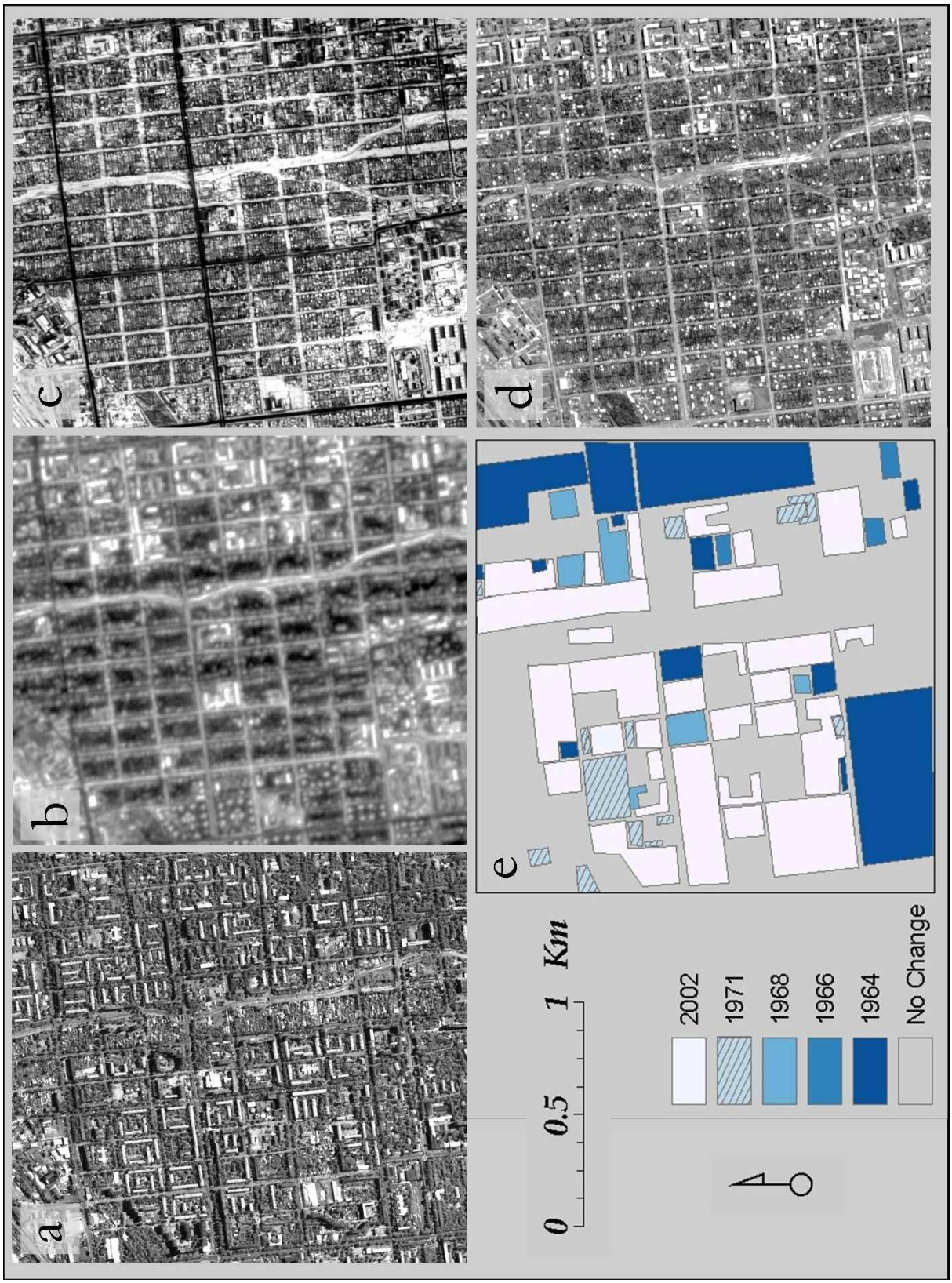

Figure 1. Almaty time-series: a) QuickBird 2002, b) Corona 1968, c) Gambit 1966, d) Gambit 1964, e) Digitised areas showing change from low-density buildings to high-density buildings.