J. King Saud Univ., Vol. 21, *Eng. Sci.* (1), pp. 7-14, Riyadh (2009/1430H.)

Mapping Waste-disposal Sites in Riyadh Using Radarsat Imagery

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(Received 27/11/2006; accepted for publication 8/7/2007)

Keywords: Radarsat, Waste-disposal, Monitoring.

Abstract. A digital SAR image from the Canadian satellite Radarsat covering the city of Riyadh, the capital of Saudi Arabia, was used to test the potential of spaceborne SAR systems for mapping waste-disposal sites. A PCI software was used to perform the various image processing operations. The results show that high resolution SAR imagery from space platforms could be a viable tool for the inventory of waste-disposal sites. This is an important conclusion for a big city like Riyadh where disposed waste should be regularly monitored in order to compact its adverse effects on the environment.

Introduction

Airborne and satellite remote sensing is now a mature technology with many benefits. Multi-spectral image processing of such data provides information about the chemical composition of the earth surface with better spatial context than non-imaging sensors can generally provide. Thus, remote sensing offers opportunities for aerial extrapolation of point measurements made in the field resulting in an increase in the area for which information can be gleaned from a given set of point measurements. Nowadays, once remote sensing data are collected, multi-spectral and spatial image processing can typically be completed on a personal computer in less time than field measurements and sample collections.

Status of Satellite Synthetic Aperture Radar Mapping

Unfortunately, what has just been mentioned pertains almost exclusively to optical remote sensing including aerial photography and satellite data as aquired by Landsat MSS and TM and SPOT HRV images. In this respect, the development of satellite SAR systems has lagged clearly behind electro-optical systems. The Landsat paradigm reoriented scientists and users toward the detection of temporal change and away from the 1960s paradigm of photographic analysis of the ground. Understandably, the inertia generated by three decades of focus on photographic and visible/infrared scanning translates today into a scientific community whose familiarity with radar data lags far behind its understanding of data sets derived from sensors operating in the visible, near-infrared (VNIR) and thermal infrared (TIR) spectra. Data from all spectral regions, including the microwave region, produce unique, and in some cases, vital information for Earth system sciences. The determination of the potential information content, however, and means of extracting that information from synthetic aperture radar (SAR) images require gigantic developments. As a result of the global priority for electro-optical sensor data, there has been a dearth of accessible satellite SAR data for translating airborne applications to validated satellite applications. Consequently, the science community has had delayed learning curve for using SAR data, a major part of which has involved research in data interpretation such as those acquired by Seasat (1978), SIR-A (1982), SIR-B (1984), ERS-1 (1995), Almaz (1992), JERS-1 (1995) and other experimental SAR systems. With the launch of the high resolution Canadian SAR system Radarsat in 1995, a new possibility emerged as to the utilization of space SAR data for mapping and/or monitoring the earth surface. Generally speaking, because radar data costs less than 5 US dollars/km^2 coverage (as opposed to perhaps 200-300 US dollars/km^2 for aerial photographs), earth scientists are expected to pay particular attention to using data from this third generation satellite SAR sensor for earth surveys and monitoring.

The present paper is concerned with the investigation of Rasarsat-1 data for waste-disposal site monitoring in the city of Riyadh, Saudi Arabia. The problem of waste-disposal is one of the major concerns for local authorities of big and fast-expanding cities such as Riyadh. The nature of the problem, the data used, the procedures followed and the results obtained will be fully explained and analyzed. A set of conclusions as regards the use of satellite-borne synthetic aperture radar data for waste-disposal site mapping in the city of Riyadh are then drawn.

Use of Remote Sensing for Waste-disposal Site Monitoring

In particular, remote sensing mapping can aid in the evaluation of temporal changes in land use within and near hazardous waste and sanitary landfills. The effects of landfill leachate contamination, for example, are also detectable with remote sensing techniques. Thus, by mapping and monitoring waste sites in large cities such as Riyadh, many benefits are gained. First, environmental engineers will have another source of information to consider which increases the possibility of making the right decision in their environmental issues. Second, suitable sites for future use can be determined based on more sound basis. Third, urban expansion towards such sites could be accurately monitored, thus preventing the evolution of future environmental problems. Fourth, in this era of information technology, waste site maps could well contribute towards the creation of useful and efficient layers of city or county GIS.

Some Experiences Gained with Waste-disposal Site Surveys

Indeed, many publications have appeared in the literature addressing the role remote sensing can play in the inventorying and assessment of waste-disposal sites. As examples, Barnaba *et al*. (1991) investigated the use of aerial photographs in county inventories of waste disposal sites. For this purpose, multi-date historic aerial photographs were used in conjunction with field surveys to analyze, detect and categorize hundreds of previously unidentified waste sites for remedial actions. The procedure adopted comprised pre-survey work, acquisition of aerial photography, development of appropriate classification system to be used in the inventorying process, survey of public information, airphoto analysis and georeferencing, site prioritization, and finally the implementation of a monitoring program. The technique was described as "effective" in performing comprehensive inventories of waste disposal sites over county-size areas.

Lyon (1987) reported the results of an investigation concerned with the use of a number of data sources, namely old maps, aerial photographs, other remote sensor data and advanced evaluation techniques to better identify and inventory soil, hydrologic and site vegetative states which are believed to be a positive indicator of hazardous waste sites. Measurements on these data sources were conducted to establish both the change in size and characteristics of landfills over time. Siting, monitoring, closure and rehabilitation of abandoned hazardous waste sites were reported to have been possible through the use of these data.

On the more advanced side, the use of digital photogrammetric methods is proving to be of advantage in assessing solid waste landfills and hazardous waste sites. Vincent (1994), for example, carried out detailed topographic mapping by high resolution digital photogrammetric methods to yield high resolution digital terrain models (DTMs). These were used as input to surface run-off models to predict where contamination from solid waste and toxic landfills was most likely to occur and where depressions on the landfill may collect and concentrate run-off. Also, two DTMs collected at different dates on a site could be used as input to cut-and-fill estimate software for accurate computation of volumetric changes in landfills due to continued in-filling or to land subsidence. Visible simulation software could also be used in conjunction with DTMs to produce simulated perspective views of landfill from any user-selected position.

Use of multispectral remote sensor data and digital image processing revealed that it is possible to map solid waste landfills (specially those aspects related to ferric and ferrous oxides that are by-products of low-temperature geochemical processes caused by contaminants in wastes), and vegetation stress (e.g. chorosis) which could be indirect indicators of liquid and gaseous waste leaks. Active radar and thermal infrared (TIR) remote sensor systems had also been used to map buried waste disposal sites and potentially hazardous and non-hazardous fluid leak plumes. In this respect, Weil *et al.* (1994) stated that these sensors could be used to investigate and map tens of acres per day for the purpose of locating waste sites when used in a combined format comprising rapid survey techniques and manual data analysis. Case studies from West Coast Air Base in California (U.S.A.) to locate 89 suspected underground storage tank locations, and from New Maxico, where a 33-year old buried waste site was successfully located and characterized using radar and thermal infrared (TIR) sensors, showed that these non-conventional sensors also contribute positively to mapping waste-disposal sites.

The role of non-metric small format camera photography (the so-called low-cost mapping system) in surveying waste sites was described by Warner *et al.* (1994). Photographs taken with a hand-held standard 35 mm camera were enlarged using a commercial color laser-scan electronic copier. Stereoscopic and monoscopic measurements were made on the enlarged photos using a low-cost tablet digitizer and ordinary photogrammetric procedures. In one of the three waste sites surveys conducted by Warner, the surface areas of five filteration lagoons (which were newly constructed at the base of rural waste site) were measured. The absolute positional accuracy requirement was believed to be in the order of ± 2 m. Control points on the site were digitized from a 1/5000 scale map, with 5 m contour interval. Coordinate accuracies of $\sigma_x = \pm 2.3$ m and $\sigma_x = \pm 2.1$ m were obtained which were believed to be much close to the required accuracy figure, thus demonstrating the effectiveness of low-cost non-metric photogrammetry in mapping waste sites.

Waste-disposal in Riyadh

Riyadh, the capital of Saudi Arabia, has a population of more than 4.5 million increasing at a rate of about 8% annually. The city has abundant refuses that must be managed and controlled daily. About 400 trucks are involved in the process of carrying different wastes to landfills situated outside the outskirts of the city. Each truck empties its contents about five times daily. According to the General Clearing Department of Riyadh Municipality (CDRM), at each landfill, heavy machines spread and compress the wastes to a thickness of 2.5 m. The formed waste is then covered with a layer of selected soil to about 0.5 m thickness. The percentages of the materials of the landfill are shown on Table 1.

Table 1. Types and percentage of input materials to landfills in Riyadh

Type of Material	Percentage
Foods	34%
Papers	28%
Metals	16%
Wood	10%
Plastic	2%
Glass	2%
Rubber	1%
Textiles	1%
Others	6%
Total	**100%**

Sources of these waste materials are farms, houses, companies, streets, hospitals, workshops, factories and construction sites. With time, the area and height of the landfill will increase, thus necessitating landfill closure and occupation of another site. According to CDRM, most sites remain active for a number of years before being closed. Obviously, as years drag on, careful measures must be taken to protect the environment from the adverse effects these landfills are likely to have on it.

As far as liquid waste is concerned, about 18,750,000 liters/day of water accumulating in the city is collected and pumped into an open area (pit). Like its solid counterpart, liquid waste can cause serious damage to the environment and consequently water pits must be carefully selected and monitored.

The CDRM stresses that there is a real need to monitor these sites. There are four of these in Riyadh shown in Table 2, three are landfills and one is a pit.

Table 2. Known landfill and pit in Riyadh City and related information

Waste	Location	Input (10^6/year)	Area	Height	Status
Landfill	Al-Solay	Solid	N.A	19 m	Inactive
Landfill	Al-Solay	Solid (1.5ton)	1.5 km^2	11 m	Active
Landfill	Okadh	Solid (0.8 ton)	1.0 km^2	13 m	Active half a day (close to urban)
Pit	Al-Solay	Water 70001	N.A.	N.A.	Active

N.A. → not available

The contents of Table 2 ought to be somewhat alarming to urban management authorities of the city, especially as regards the closeness of the landfills to urban areas. One of the landfills of Table 2 is believed to be inactive. CDRM did not confirm or deny the possible existence of other inactive waste sites which might be close to or within residential, industrial or commercial areas of the city. Therefore, the aim of this experiment is to attempt to inventory and assess waste-disposal sites using active remote sensing systems as exemplified by Radarsat SAR apparatus.

Data Used and Test Area

The data used in this experiment consists of an orthorectified F2 mode Radarsat image (resolution 12.5 m) of Riyadh City. Radarsat-1 is an advanced earth observation satellite project developed by the Canadian Space Agency (CSA). It was launched by NASA in 1995 from Vandenburg Air Force Base in California to monitor environmental changes and to support resource sustainability. Some potential applications of Radarsat-1 data include sea-ice monitoring, acquisition of daily ice charts, extensive cartography and some other non-cartographic applications. Under the auspices of CSA, Canada had been responsible for the design and integration of the overall system, for its control and operation in orbit, and for the operation of the data reception and processing stations located in Prince Albert, Saskatchewan and Gatineau (Quebec). Radarsat is equipped with an advanced C-band SAR wavelength (λ = 5.6 cm), right-looking and steerable antenna and multi-mode imaging capabilities.

The test area covers the city of Riyadh and surroundings from Alnaseem in the east to Dariyah in the west and from Al-Haer in the south to Almursalat in the north. Originally, the data was provided to the author by the Saudi Remote Sensing Center of King Abdulaziz City for Science and Technology (KASCT) in Riyadh. Later on, the data was digitally processed using a PCI version 10 software (the PCI software is a Canadian commercial image processing package, it includes various modules, these are FOCUS, Orthoengine, Moduler, FLY and EASI). The use of Radarsat imagery requires several types of processing to produce the orthorectified image. A digital elevation model was generated using stereo-SAR techniques, and then this DEM together with ground control points were used to orthorectify the Radarsat F2 mode image.

For waste-disposal mapping, the method of approach consists of using digital image processing techniques in order to map and verify the existence of different kinds of waste-disposal sites using ground truth samples as input to a supervised classification algorithm in the PCI software version 10. The procedure goes along the following lines:

(i) SAR segmentation. This is the process of segmenting (i.e. dividing) images based on what is termed "region image segmentation algorithm" in the software. SAR segmentation is meant to ease SAR image classification and to make the process less demanding computationally.
(ii) Supervised classification.
(iii) Saving the waste-disposal results in a vector layer.
(iv) Superimposition of the waste-disposal layer to the SAR image.

Results and Analysis

First, the imagery is segmented using librarian algorithm "SARSEG" of the PCI. Figure 1 shows the segmented F2 mode image of Riyadh. Training sites were then selected based on a similar work over Riyadh carried by Ali and Algarni (1997) using Spot-2 images of the test area and ERDAS version 6.1.

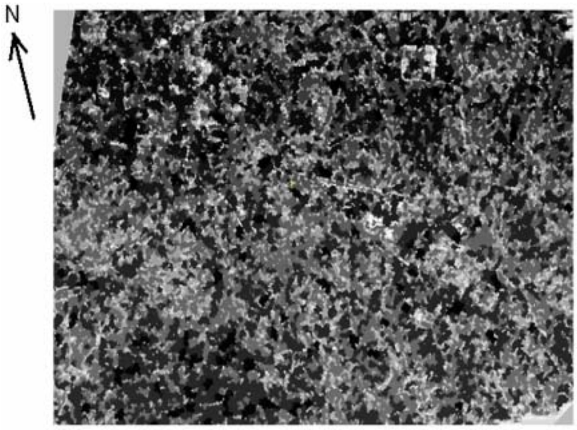

Fig. 1. The segmented image F2 of Riyadh (scale 1:200,000).

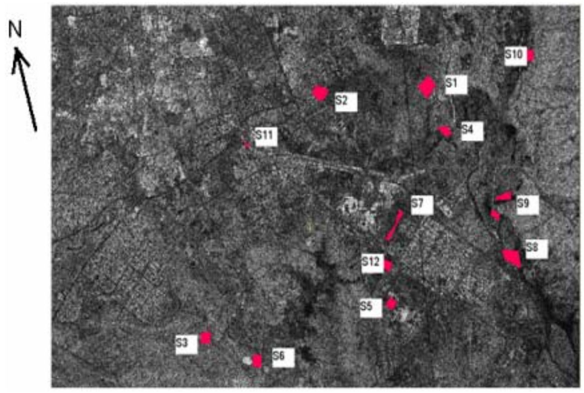

Fig. 2. Waste-disposal site areas in Riyadh from Radarsat F2 image (shown in red, scale 1:200,000).

Fig. 3. Construction waste-disposal sites S8 and S9.

Here, three training sites (or samples) were used that represent waste sites on the original image. These are sites whose nature, locations and characteristics are known a-priori. Then, a supervised classification (i.e. one that is based on input information from the selected training sites) is carried out using the original image and the segmented image as constrains (the software use the training samples to find out the similar regions in the original image, and save the resultant regions as a vector layer). The resultant waste disposal areas are shown in a superimposed layer as red color patches in Fig. 2.

The results of the classification showed 12 waste-disposal sites in the city of Riyadh, most of which lie in the south-eastern part of the city. Subsequent field verifications confirmed the existence of these sites. Figures 3 to 6 are terrestrial snapshots collected during field visit to the test area to show the reader the nature of these waste sites. The particulars of these sites are as follows:

1. Sites S1, S2, S3, S4, S5 and S6 are known waste-disposal sites and were detected by Ali *et al*. (1997) using a Spot-2 multi-channel image over the test area.
2. Sites S8 and S9 are construction waste sites (Fig. 3).
3. Sites S7 and S12 are industrial waste sites "pits" (Fig. 4).
4. Site S11 shows industrial waste from a cement factory (Fig. 5).
5. Site S10 shows a large construction waste site (Fig. 6).

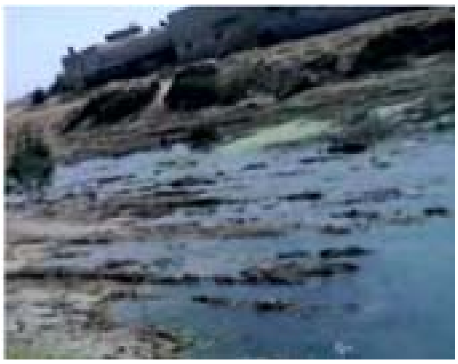

Fig. 4. Industrial waste-disposal sites S7 and S12.

Fig. 5. Industrial cement waste-disposal site S11.

Fig. 6. Construction and hazardous Waste-disposal site S10 (near Alaan mountain).

The results of this experiment show the efficiency of Radarsat imagery for waste-disposal site monitoring. These could have been better if polarimetric multi-channel SAR images are used instead of this single-channel test image. Unfortunately, these were not available for the test area of this experiment.

In Fig. 2, it can be noted that urban expansions are close to almost all waste-disposal sites which raises an alarm to urban planners and managers in the city to take appropriate measures toward preventing possible hazardous effects of these sites on residential areas close to them. The extent of this problem would have been somewhat more difficult to visualize or apprehend without the use of remote sensor data as conducted in this experiment.

Conclusion

In conclusion, therefore, it can be mentioned that the use of spaceborne SAR imagery in conjunction with digital image processing techniques could be a viable tool for the inventory of waste-disposal sites. This is an important conclusion for a city like Riyadh where population growth stands at 8% annually which necessitates the development of a continuous monitoring program of this phenomenon and its impact on human life and the infrastructure of the society. Contrasted with the effort- and time-intensive ground survey work, SAR remote sensing can prove to be a cost-effective method for solving complicated and dynamic environmental problems such as waste-disposal site mapping and inventorying. The author, therefore, appeals to relevant authorities in Riyadh (and other major cities in the region) to consider exploiting the undoubted benefits of this technology in their respective works. Taking into account that radar imagery costs less than five dollars per square kilometre coverage, it seems worthwhile for government and private sector authorities to contemplate waste-disposal site surveys and inventorying from high resolution spaceborne SAR images as exemplified by Radarsat images used in the present study.

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ترسيم مواقع النفايات الرياض باستعمال صور رادارية من رادارسات

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ملخص البحث. أخضعت صورة رادارية من التابع الكندي رادارسات تغطي مدينة الرياض لعدد من التجارب المعملية بغرض دراسة و تحديد إمكانية استعمال صور الرادار الفضائي ممثلاً في نظام رادارسات لترسيم مواقع النفايات في هذه المدينة، استعملت لهذا الغرض حزمة البرامج الحاسوبية PCI لتنفيذ عمليات المعالجة الرقمية المختلفة الخاصة بالبحث. وقد أثبتت النتائج أن صور الرادار الفضائي(ممثلة في نظام رادارسات) تصلح لمعرفة وتحديد وترسيم مواقع النفايات في المدن الكبرى مثل الرياض. وتعتبر هذه النتائج من الأهمية بمكان حيث تحتاج الجهات المسؤولة في مثل هذه المدن لوضع الخطط والسبل للمراقبة المستمرة والدائمة للنفايات وتحديد ومحاربة تأثيرها السلبي على البيئة.