Remote Sensing Applications: Society and Environment 5 (2017) 27–35

Contents lists available at ScienceDirect

Remote Sensing Applications: Society and Environment

journal homepage: www.elsevier.com/locate/rsase

Discriminating Uranium and Copper mills using satellite imagery

Lalitha Sundaresan[a,*], S. Chandrashekar[a], Bhupendra Jasani[b]

[a] *Visiting Professors, International Strategic and Security Studies Programme, National Institute for Advanced Studies (NIAS), IISc Campus, Bangalore 560012, India*

[b] *Department of War Studies, King's College London, London, UK*

ARTICLE INFO

Keywords:
Uranium mill
Copper mill
Spatial Signatures
Discriminant function

ABSTRACT

Identifying uranium mills from high resolution commercial satellite images has assumed significance in recent years because of non-proliferation concerns. Studies have shown that it is difficult to identify Uranium mills through remote sensing methods that use only spectral signatures. In this communication we suggest an approach that relies only on spatial signatures of the equipment used in the extraction process as an alternative. Since the extraction of Uranium and Copper have many similar features especially where Copper is extracted from low grade ore or from copper tailings, there could be ambiguity in identifying a Uranium mill from high resolution commercial satellite images. In an earlier work carried out by the authors and summarized in this paper as well we had proposed a separation between copper and uranium mills based on the spatial signatures of equipment that is unique to the copper milling process. In this paper we suggest some improvements to the methodology outlined by us in our earlier work. In addition to the other features used to separate Uranium and Copper mills we bring in the dimensions of common equipment used in both processes as an additional dimension to improve the robustness of our classification. This technique is applicable only where the extraction is done in a mill and not where Uranium is extracted by in situ leaching methods.

1. Introduction

Uranium in its varied forms is a very important nuclear material. Since Uranium has military as well as civilian uses, monitoring the uranium production on a global basis is essential. The International Atomic Energy Agency (IAEA) an independent intergovernmental, science and technology-based organization (https://www.iaea.org/about/mission), that serves as the global focal point for nuclear cooperation verifies through its inspection system that States comply with their commitments, under the Non-Proliferation Treaty and other non-proliferation agreements, to use nuclear material and facilities only for peaceful purposes.

Following the IAEA suggestion (Jasani, 1990) in 1990 that civil remote sensing satellites could be used to monitor multilateral agreements such as the 1970 Treaty on Non-Proliferation of Nuclear Weapons (NPT) a number of studies (Jasani et al., 1996; IAEA, SRDP-R256, 1998; IAEA, SRDP-R269, 2000) on the use of commercial satellite imagery in safeguards procedures were carried out under the UK and German Support Programmes to the IAEA. Basically in these studies various elements of the nuclear fuel cycle were investigated in order to determine “keys” for each of the nuclear facilities so that an image interpreter could identify them in a satellite image. A number of recommendations (http://www.iaea.org/OurWork/SV/Safeguards/safeg_system.pdf) were then made by the Director General's Standing Advisory Group on Safeguards Implementation (SAGSI) to strengthen the IAEA's safeguards procedures that included the use, by the Agency, of open source information such as images acquired by commercial satellites. Later the early part of the fuel cycle, uranium mines and mills, were investigated and a preliminary report (Jasani, 2009) was prepared for the Research Centre, Jülich, Germany. The Agency is now using this technique to confirm declarations made by States under their safeguards agreements with the Agency, as a pre-inspection planning tool and to look for undeclared nuclear activities (Chitumbo et al., 2002).

Identifying a Uranium exploration facility or a Uranium mill, was difficult during the early years of remote sensing because of the low spatial and spectral resolution of satellite sensors. Attempts were made by the CIA, USA to monitor Uranium mining and milling activities in the Former Soviet Republic (FSR) and also estimate the production (Joint Photographic Intelligence Report, 1959) based on the ore grade and the size of the tailings ponds using aerial photographs. Later low resolution satellite images became available with the launch of the CORONA satellite by the USA. These studies also helped to define what can be learnt about Uranium mining and milling using satellite imagery leading to the publication of the Photo Interpretation Handbook (Photo Interpretation Student Handbook, 1996).

* Corresponding author.

http://dx.doi.org/10.1016/j.rsase.2016.12.002
Received 6 May 2016; Received in revised form 2 December 2016; Accepted 28 December 2016
Available online 20 January 2017

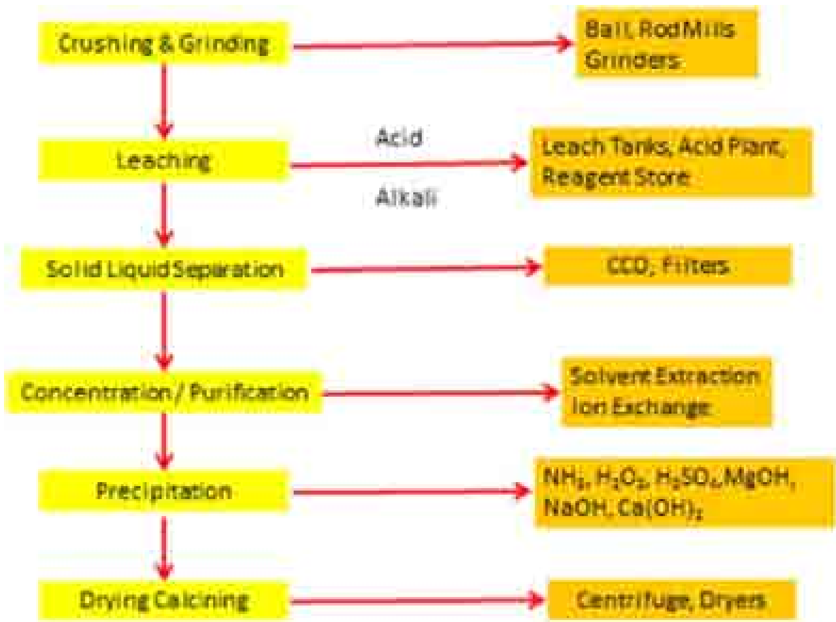

Fig. 1. Steps in Uranium extraction.

With the availability of hyper-spectral images and advanced image processing techniques, there has been renewed interest in identifying a Uranium mill using spectral signatures (Lévesque et al., 2001; Neville et al., 2001; Leslie et al., 2002; Jasani et al., 2005). A systematic study to evaluate the use of satellite remote sensing for identifying Uranium mines and mills was carried out by Researchers at the Sandia National Research Laboratory (Stork et al., 2006). Using the Ranger Uranium mill in Australia as a case study, the report looked at the potential use of multi-spectral as well as hyper spectral data from a number of remote sensing satellites to determine whether there were any unique features of a typical Uranium mining and milling operation. The study concluded that although hyperspectral data could help in categorizing different bodies of ore into very broad types, the occurrence of Uranium within such an ore body is so small that it provides no visible signature to the satellite sensor. The study also concluded that hyper-spectral data could not distinguish between uranium milling processes from other milling processes such as that of copper, zinc, vanadium, phosphorous and Rare Earths. Further the study pointed out that while high spatial resolution satellite systems such as Quickbird lack sufficient spectral resolution to uniquely identify many materials, spatial information provided by these systems could complement information obtained from high spectral resolution systems such as Hyperion.

Taking the cue from the above study, a set of functional keys and signatures based upon observations of a large number of Uranium milling operations across the world for which Google Earth (GE) imagery and associated process flow diagrams were readily available was developed more recently by Chandrashekar et al.(Chandrashekar et al,.2015a). Satellite imagery especially Google Earth (GE) images were then studied to generate a set of interpretation keys. These keys link the operations in the mill sites to the observables in the satellite image. The shapes and sizes of the features seen and their position in the process chain provided a set of spatial signatures that could be used to identify a Uranium mill. The most commonly occurring features across the sample set along with their signatures were then used as the basis for the development of a decision tree. The method also provided a way in which one could make an estimate of the production capacity of Uranium mills (Chandrashekar et al., 2015b; Sundaresan et al., 2015).

The investigation showed that the extraction process of copper was very similar to that of uranium extraction process particularly where copper was being extracted from its tailings or when the ore grade was low. Some of the equipment used in both these extraction processes was similar. It was therefore important to make sure that a copper mill was not wrongly labeled as a uranium mill and vice-versa. Towards this the study identified spatial features such as an electro-winning building associated with Copper mills that is not present in a Uranium mill. This helped to identify a uranium mill with more confidence.

In this paper we present an extension of the above study to identify a Uranium mill and discriminate it from a Copper mill. This discrimination is made possible by taking into account the sizes of common equipment used in the extraction processes of both Uranium and Copper. We show that the differential sizes of Counter Current Decantation (CCD) units seen in both Uranium and Copper mills can be used to discriminate the two extraction facilities. This together with the spatial signatures of electro-winning building and power plants invariably present in a copper mill make the decision algorithm for identifying a uranium mill and discriminating it from a copper mill, a robust one.

The spatial signatures and the approach suggested could be suitably modified for use as primitives for object based image analysis (Blaschke, 2010; Navlur, 2007). This paper does not deal with heap leaching or with In Situ Leaching [ISL] operations which may involve different observables in the satellite imagery. It only covers general hydrometallurgical milling operations involved in Uranium extraction. Since ISL mills also have some recognizable surface features (Jasani, 2009), an extensive investigation of ISL mines and mills across the world will help to identify spatial signatures for such sites.

2. The Uranium extraction process

The geological conditions under which Uranium bearing ores can be found across the world have been extensively researched and documented (IAEA Technical Report Series No.359, 1993). The various steps involved in mining, beneficiation of the ore and its further processing into the commonly used yellowcake form has also been studied in great detail. Uranium Mining is carried out either through underground or open pit mines.

The nature of the deposit dictates the choice of the process adopted at a particular site.

An overview of the typical processes used for the extraction of Uranium is in Fig. 1. The figure also shows typical equipment used to