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Mapping of Siltations of AlKhod Dam, Muscat, Sultanate of Oman Using Low-Cost Multispectral Satellite Data

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***Abstract*—**Remote sensing plays a vital role in mapping of resources and monitoring of environments of the earth. In the present research study, mapping and monitoring of clay siltations occurred in the Alkhod Dam of Muscat, Sultanate of Oman are carried out using low-cost multispectral Landsat and ASTER data. The dam is constructed across the Wadi Samail catchment for ground water recharge. The occurrence and spatial distribution of siltations in the dam are studied with five years of interval from the year 1987 of construction to 2014. The deposits are mainly due to the clay, sand and silt occurrences derived from the weathering rocks of ophiolite sequences occurred in the Wadi Samail catchment. The occurrences of clays are confirmed by minerals identification using ASTER VNIR-SWIR spectral bands and Spectral Angle Mapper supervised image processing method. The presence of clays and their spatial distribution are verified in the field. The study recommends the technique and the low-cost satellite data to similar region of the world.

***Keywords*—**Alkhod Dam, ASTER Siltation, Landsat, Remote Sensing, Oman.

I. Introduction

RECHARGE dams increases the groundwater potential. Dams constructed across the wadies in arid region increases the availability of groundwater to domestic and irrigational purposes. The coastal regions of Sultanate of Oman decline in groundwater level, considerable reduction in well yields and deterioration in water quality [1], [2]. To overcome, a total of 34 dams were constructed for this purpose by the Ministry of Regional Municipalities and Water Resources (MRMWR) of Oman. In which, 21 dams are constructed across major wadies parallel to the coast. Most of the dams are silted now mainly due to wadi flow after flash floods in catchments while the collection of rain water in upstream parts of mountains and drain flow towards coastal zones, the downstream. During the flash floods, the wadies flow water carry gravels, sand, silts etc. towards the downstream and deposits them at dams constructed across the flow direction. It is important to study the occurrence of silts in the dams

The remotely sensed satellite data are more useful in mapping of resources and monitoring of environments of earth surface. The spectral bands of visible and near infrared (VNIR) and short wavelength infrared (SWIR) of low-cost multispectral satellite data provides useful information to map such resources. Especially, the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) which measures visible reflected radiation in three visible and near infrared spectral bands (VNIR, between 0.52 and 0.86 µm, with 15-m spatial resolution) and infrared reflected radiation in six short wavelength infrared spectral bands (SWIR, between 1.6 and 2.43 µm, with 30-m spatial resolution) are more significant to such applications. The spectral bands in the SWIR region of the ASTER sensor are relatively more compare to the spectral bands of other sensors which enhances the mapping of siltations of dam. Particularly, the spectral bands are more useful for mapping of clay and argillic minerals, carbonates, ferric and ferrous oxide deposits [3], [4]. This study attempts to use the satellite data to map the occurrence and spatial distribution of siltations of AlKhod Dam located near AlKhod town in the lower reaches of Samail Catchment, north of Muscat (see Fig. 1). The study also uses the Landsat satellite data of five years interval to find the changes in the siltations since 1987 to 2014.

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II. AlKhod Dam

The present study mainly focuses about the occurrence of siltations of AlKhod Dam which is constructed near AlKhod town in the lower Samail Catchment, situated in the Batinah coastal plain north of Muscat (see Fig. 1). The dam is the oldest and largest recharge dam in Oman that was constructed between December 1983 and March 1985. Samail Catchment covers an area of 1,635 km2 and drains water from the highlands in Oman's interior into the Batinah coastal plain where AlKhod Fan is located. It is a type of earth dam has 5,100 m crest length and up to 11 m high. The spillway of the dam section is 3,000 m long, and the total reservoir area is 3.2 km^2. The original (1988) unsilted reservoir capacity was approximately 11.5 millionm^3. The dam is equipped with 11, each with a diameter of 1.22 m for downstream discharge purposes through a 3,000 m long, 19 m wide stilling basin, made of rock-fill gabions [5]. Annual rainfall varies between more than 300 mm in the highlands to less than 100 mm in the coastal plain [5]-[8]. For the past 24 years, the area has experienced several episodic floods. The wadi gaging station (located at 23°34′N latitude and 58°7′E longitude, altitude of 78 m) is 4 km upstream of the dam reservoir. Unfortunately, there are no data on suspended loads, bed loads, and even the turbidity of water at the gaging station. The embankment was overtopped during three major floods: in March 2007 and during Cyclone Gonu in June 2007 and Cyclone Phet in June 2010[5]-[7], [9]. The last two floods incurred enormous damages to the populated area downstream of the dam. The maximal recorded flow rate at the gaging station was 178 m^3/s [5]. The landscape of the area adjacent to the dam is a paved desert, moderately dissected by channels and intermittent streams, and the soils of the reservoir are of an alluvium parent material influenced by limestone and ophiolites derived from the Al-Hajar mountains [5], [10]. Prior to the construction of the dam, the dominant soils of the reservoir area were Gypsids, Calcids, and Torriorthents of a very gravelly or sandy skeletal nature [11]. Detailed informations on the geology and hydrogeology of the region are reported in [5]-[7], [12], [13].

Fig. 1 Google location of the Alkhod Dam in Oman

III. Geology of the Study Area

Samail catchment is a full member of ophiolite sequences consist of dunite, harzburgite, gabbros, sheeted dykes and pillow lavas. The geology in and around of the dam consists of crystalline bedrock formations, mainly ophiolites, mantled by unconsolidated alluvium deposits. The geology of the area is given in Fig. 2. The Quaternary alluvium unconformably overlies the ophiolites along the drainage course of the AlKhod Fan. They consists mainly a mixture of poorly sorted rock gravels, sands and minor clays. It makes the main source for the alluvium formed as a result of ophiolites weathering. The siltations of the dam mainly consist of clays, the derivatives of weathered ophiolites deposited as layer in different thickness in the dam.

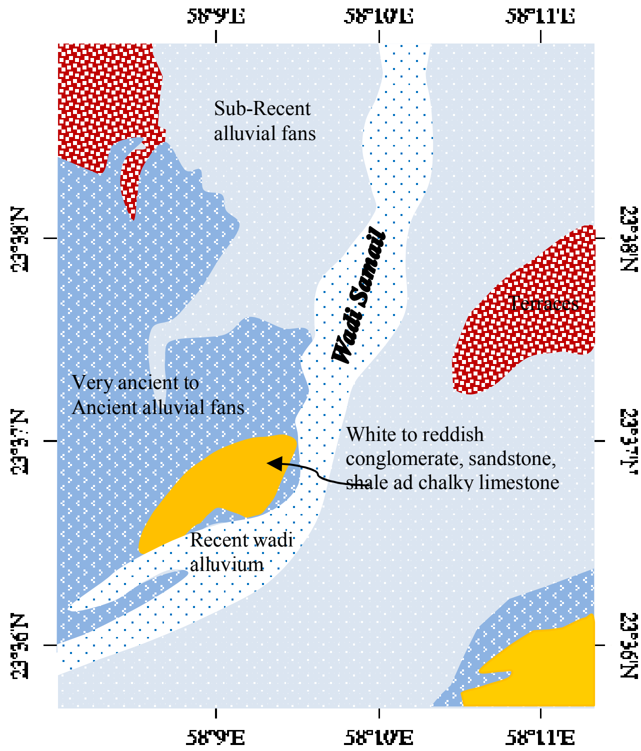


Fig. 2 The geology in and around of AlKhod dam

IV. Satellite Data and Methods

In this study, the nine VNIR–SWIR spectral bands of ASTER were chosen and processed to the areas of interest to map the siltation occurred in the Al Khod dam using ENVI (5) and ArcGIS (10.1) software's. More details on ASTER and its sensor characters are reported in Rajendran et al. (2012) and Rajendran and Nasir, (2013a) and can be referred [4], [14]. The occurrence and spatial distribution of siltation of the dam were carried out by developing color composites and unsupervised spectral angle mapper digital image processing methods. The changes in the occurrence and spatial distribution of siltation are studied using the Landsat satellites data of the years 1987, 1990, 2000, 2005, 2010 and 2014. The processed images are interpreted and verified in the field.

V. Image Analysis

The siltation of Al Khod dam is mainly deposited with the clays [5], [6] and mapping of clay minerals of the dam lead us to give details on the possible occurrence and spatial distribution of silts in the dam. Many authors have used the image processing methods such as color composite, band rationing, decorrelation stretch, principal component analysis (PCA) and spectral angle mapper (SAM) etc. to map soil, rock types, structures, agriculture and to detect minerals of rocks over different satellite data of the multispectral sensors including Landsat TM and ETM, ASTER [3], [14]-[16]. Also, there are several published articles on the applications of ASTER data to map minerals of the rock [17]-[20]. In this study, to map the siltation of the AlKhod dam, the nine ASTER VNIR-SWIR bands were studied by developing false color composite image. The supervised classification method called Spectral Angle Mapper (SAM) is used to extract the minerals informations in and around of the dam [17], [18], [20]-[22]. The results RGB color composite and SAM are given in Figs. 3 and 4.

VI. Results of the Study

Researchers have previously outlined the use of red-green-blue (RGB) image to show different lithology and resources of earth surfaces [14], [15], [17], [18], [23]-[27]. The study of spectral absorptions of clay and carbonate minerals leads to develop a color composite RGB image. In the RGB color composite image (R:8, G:3, B:1; Fig. 3), the ASTER bands 1 and 3 were chosen to show the different rock types/ formations occurred in and around of Al Khod dam. In which, the ASTER band 8 was selected to distinguish the OH and CO3-bearing altered minerals found in the dam. The resulted image clearly shows the occurrence of the siltation of the dam appears in pink color due to the absorption by OH molecules present in clay minerals and CO3 contents in carbonate bearing minerals. The different major Quaternary formations in different tone viz. dark blue (Qtz), reddish brown (QFw-x) and dark brown (Afy). The variations in tone are due to the occurrence of iron in different proportion in the weathered surface of the rocks.

While the interest is focused on the siltation of the Al Khod dam, the Spectral Angle Mapper (SAM) method working based on the "Spectral Hourglass" scheme [4], [20], [21], [28] available in ENVI 5 image processing and analysis software (http://www.exelisvis.com) is applied on nine ASTER VNIR-SWIR spectral bands to identify the minerals in each pixel of image of the region. The details about SAM and processing methods are also discussed and reported [4], [20], [21], [25]-[29]. Fig. 4 is the SAM classified image of the region. The classified image (Fig. 4) shows the occurrence and spatial distribution of OH and CO3 bearing clay and carbonate minerals in green color that deposited in the dam. The occurrence of magnesites and dolomites in gravels of harzburgites appear in blue color. The pixels of carbonate, viz. magnesite and dolomite minerals are found more in the Quaternary formations consist of gravels of harzburgites [30]. The occurrence and spatial distribution of water and hydroxyl molecules bearing clay minerals are appear in cyan color. These are associated with the carbonate minerals (blue color). The occurrences are due to the alteration of the gravels of harzburgite. In field, the regions are identified as harzburgites gravels which is highly altered. The SAM image clearly shows the presence of clay minerals deposit in the dam.

VII. Occurrence of Siltations from 1978 to 2014

To understand the spatial distribution of the siltation of the Al Khod dam over the year 1978 to 2014, we studied and interpreted the RGB (4, 3, 2) images of Landsat satellites (Fig. 5). The images of different periods show the gradual increase of siltations (white in color) in the dam. The increase of siltation in the dam is mainly due to deposits of clays, silt and sand derived from Samail catchment during the rainy/ flood seasons.

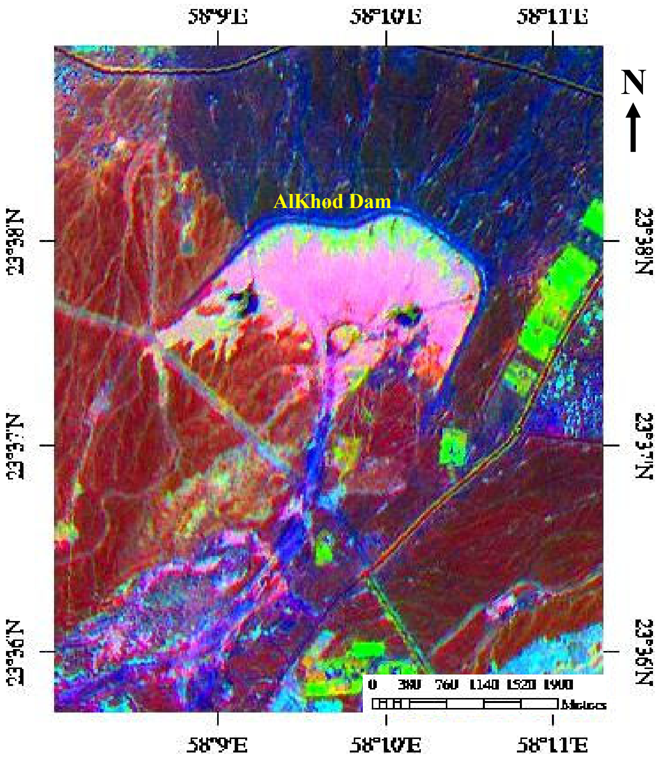


Fig. 3 Decorrelated image of ASTER spectral bands 8, 3, 1 show the occurrence and distribution of different lithology and carbonates in the AlKhod dam in the study area

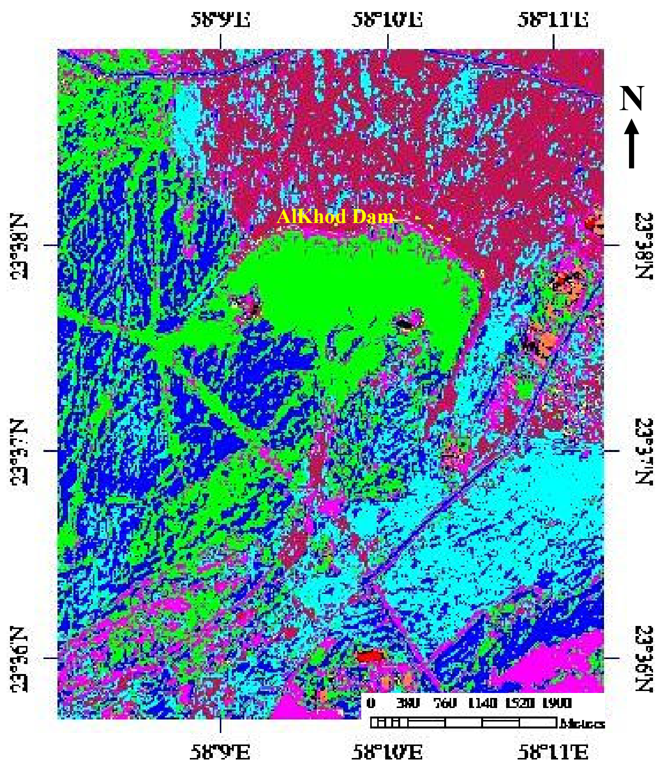
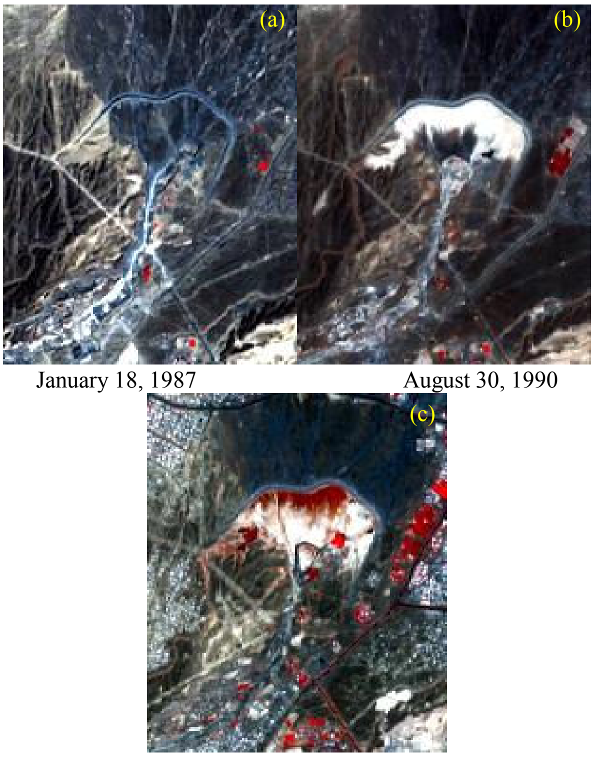


Fig. 4 SAM image of the study area

VIII. Field Study

A field work is carried out in and around of the dam to confirm the study, which shows the occurrence of top soil and vegetation in the region. Occurrence of clay and top silty cake are observed with numerous local depressions in the dam (Fig. 6). The deposit shows variation in the occurrences of silt, clay, sand and gravel contents with depth. The silt and clay are in different thickness with the sand and gravel contents in the dam. The top soils of the upward side of dam consists relatively low clay deposits and occur with more gravels and sands. In the downward side of the dam, their occurrences are more in thickness are observed. The deposits are thin alternate laminae or layers shows graded bedding. The gravels are cemented by $CaCO_3$.



17 February, 2014

Fig. 5 (a) (c) Landsat data shows the siltation (white) and vegetation (red) in the Alkhod dam

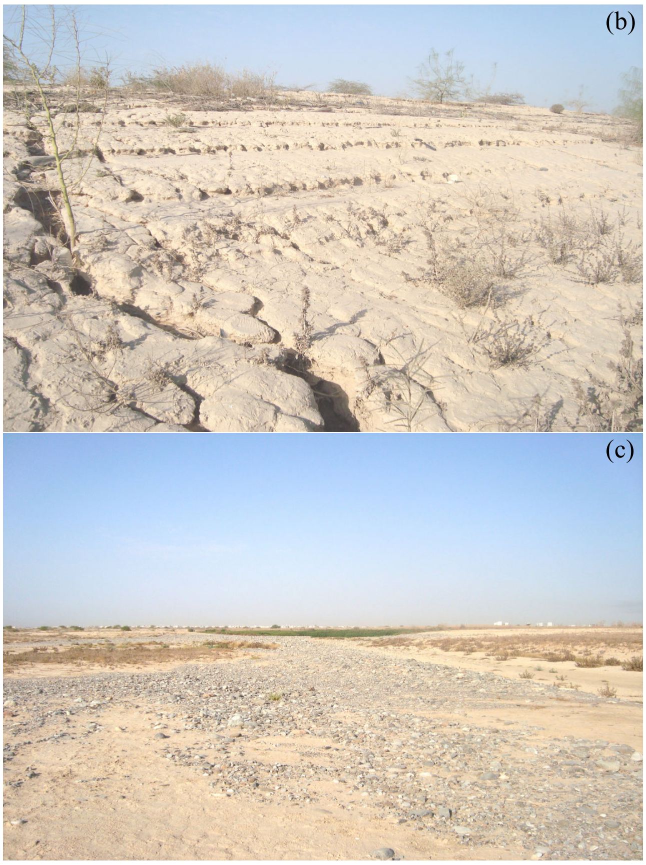


Fig. 6 Field photographs show the occurrences of siltations as (a) clays and (b) layers with (c) the sand and gravels in the AlKhod dam

IX. Conclusion

In the present research study, the occurrence of rock formations and siltations of the Alkhod Dam of Muscat, Sultanate of Oman are carried out using low-cost multispectral ASTER and Landsat satellite data. The color composite and SAM image clearly showed the occurrence and spatial distribution of rocks and silt deposits of the dam. The deposits are mainly due to the clay occurrences derived from the weathering rocks of ophiolite sequences occurred in the Samail catchment that are confirmed through the field study. The study recommends using the multispectral data and the image processing technique to map the siltations of the similar arid region.

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References

[1] A. Acra, and G.M. Ayoub, "Indicators of coastal groundwater quality changes induced by seawater infiltration", Intern. J. Environ. Studies, vol.58, pp.760–769, 2001.

[2] S. Hwang, J. Shin, I. Park, and S. Lee, "Assessment of seawater intrusion using geophysical well logging and electrical soundings in a coastal aquifer, Youngkwang-gun, Korea", *Explor Geophys.,* vol.35, pp.99–104, 2004.

[3] S. Rajendran, S. Al-Khirbash, B. Pracejus, S. Nasir, A. H. Al-Abri, T. M. Kusky, and A. Ghulam, "ASTER detection of chromite bearing mineralized zones in Samail Ophiolite Massifs of the northern Oman mountain: Exploration strategy", *Ore geology reviews,* vol. 44, pp. 121-135, 2012.

[4] S. Rajendran, S. Nasir, T. M. Kusky, A. Ghulam, S. Gabr, and M. El Gali, "Detection of hydrothermal mineralized zones associated with Listwaenites rocks in the Central Oman using ASTER data", *Ore geology reviews*, vol. 53, pp.470–488, 2013.

[5] S. Al-Ismaily, A. K. Al-Maktoumi, Kacimov, Al-Saqri, and Al-Busaidi "Impact of a Recharge Dam on the Hydropedology of Arid Zone Soils in Oman: Anthropogenic Formation Factor", *Journal of Hydrologic Engineering*, paper.04014053-1, 2013.

[6] O. Abdalla, and Al-Rawahi "Groundwater recharge dams in arid areas as tools for aquifer replenishment and mitigating seawater intrusion: example of AlKhod, Oman", *Environ Earth Sci.* vol.69, pp. 1951–1962, 2013.

[7] O. Abdalla, and R. Y. Al-Abri, "Groundwater recharge in arid areas induced by tropical cyclones: lessons learned from Gonu 2007 in Sultanate of Oman." *Environ. Earth Sci.,* vol. 63, no. 2, pp. 229–239, 2011.

[8] A. Y. Kwarteng, A. S. Dorvlo, and G. T. Vijaya Kumar, "Analysis of a 27-year rainfall data (1977–2003) in the sultanate of oman", *Int J Climatol.* doi:10.1002/joc.1727, 2008.

[9] A. R. Kacimov, S. AI-Ismaily, and AI-Maktoumi, A. "Green- Ampt one-dimensional infiltration from a ponded surface into a heterogeneous soil." J. Irrig. Drain. Eng., 10.1061/(ASCE)IR.1943-4774 .0000121, 68–72, 2010.

[10] A. A. Al-Rawas, I. Guba, and A. McGown, "Geological and engineering characteristics of expansive soils and rocks in northern Oman", *Eng. Geol.,* vol. 50, nos. 3–4, pp. 267–281, 1998.

[11] "Ministry of Agriculture, and Food and Agriculture Organization of the United Nations", *General soil map of the Sultanate of Oman, Muscat, Oman.* 1990.

[12] A. Al-Ismaily, "Coastal aquifer mapping in Oman based on performance evaluation of DC resistivity and TDEM techniques, and the integration of geophysical methods." *M.Sc. thesis, Delft Technical University, The Netherlands,* 1998.

[13] Stanly Consultants, "Feasibility report summary: The Wadi Al-Khoud aquifer recharge project", *Ministry of Agriculture and Fisheries, Sultanate of Oman,* 1991.

[14] M. J. Abrams, D. A. Rothery, and A. Pontual, "Mapping in the Oman ophiolite using enhanced Landsat Thematic Mapper images", *Tectonophysics,* vol. 151, pp. 387–401, 1988.

[15] A. P. Crosta, C. Sabine, and J. V. Taranik, "Hydrothermal alteration mapping at Bodie, California, Using AVIRIS hyperspectral data. *Remote Sensing Environment,* vol.65, pp. 309-319, 1998.

[16] S. Arunageetha, S. Rajendran, P. S. S. Kumar, R. Kumaraperumal, S. Raja, and P. Kannan, "Rapid and simultaneous estimation of certain soil physico-chemical properties by regression modelling using the hyperspectral signature of agricultural soils", *Research on Crops,* vol. 11, no. 2, pp. 339-344, 2010.

[17] S. Rajendran, S. and Nasir, "ASTER spectral analysis of ultramafic lamprophyres (carbonatites and aillikites) within the Batain nappe, northeastern margin of Oman - A proposal developed for Spectral Absorption", *International Journal of Remote sensing,* vol. 34, no. 8, pp. 2763–2795, 2013a.

[18] S. Rajendran, and S. Nasir, "ASTER Spectral Sensitivity of CARBONATE ROCKS - Study in Sultanate of Oman", *Advances in Space Research,* vol. 53, pp. 656-673, 2013b.

[19] S. Rajendran, and S. Nasir, "ASTER mapping of limestone formations and study of caves, springs and depressions in parts of Sultanate of Oman", *Environ Earth Sci.* vol. 71, pp. 133-146, 2014a.

[20] S. Rajendran, and S. Nasir, "Hydrothermal altered serpentinized zone and a study of Ni- magnesioferrite-magnetite-awaruite occurrences in Wadi Hibi, Northern Oman Mountain: discrimination through ASTER mapping". *Ore Geology Review.* vol. 62, pp. 211–226, 2014b.

[21] S.Rajendran, O. S. Hersi, A. R. Al-Harthy, M.Al-Wardi, M. Ali El-Ghali, and A. H. Al-Abri, "Capability of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on discrimination of Carbonates and associated rocks and Mineral Identification of Eastern Mountain region (Saih Hatat Window) of Sultanate of Oman", *Carbonates and Evaporites* vol. 26, pp. 351-364, 2011.

[22] F. A. Kruse, J. W. Boardman, and J. F. Hunnington, "Comparison of airborne hyperspectral data and EO-1 Hyperion for mineral mapping", *IEEE Transactions on Geoscience and Remote Sensing,* vol. 41, no. 6, pp. 1388-1400, 2003.

[23] C. A. Hecker, M. van der Meijde, H. M. A. van der Werff, and F. D. van der Meer, "Assessing the influence of reference spectra on synthetic SAM classification results", *IEEE Transactions on geoscience and remote sensing*, vol. 46, no. 12, pp. 4162–4172, 2008.

[24] D. A. Rothery, "The role of Landsat multispectral scanner (MSS) imagery in mapping the Oman ophiolite", *Journal of Geological Society of London,* vol.144, pp. 587–597, 1987.

[25] M. G. Abdelsalam, R. G. Stern, and W. G. Berhane, "Mapping gossans in arid regions with Landsat TM and SIR-C images: the Beddaho Alteration zone in northern Eritrea", *Journal of African Earth Sciences,* vol. 30, no. 4, pp. 903–916, 2000.

[26] S. Rajendran, S. Nasir, T. M. Kusky and S. al-Khirbash, "Remote sensing based approach for mapping of CO2 sequestered regions in Semail Ophiolite Massifs of the Sultanate of Oman", *Earth-Science Reviews,* vol. 135, pp. 122-140, 2014.

[27] A. M. Qaid, H. T. Basavarajappa, S. Rajendran, and J. Xu, "Calibration of ASTER and ETM+ imagery Using Empirical Line Method, a Case Study, North Eastern of Hajja Yemen", *Jour. of Geo-Spatial Information Science,* vol. 12, no. 3, pp. 197-201. 2009.

[28] S. Gabr, A. A. Ghulam, and T. M. Kusky, "Detecting areas of high-potential gold mineralization using ASTER data", *Ore Geology Reviews,* vol. 38, pp. 59-69, 2010.

[29] L. C. Rowan, and J. C. Mars, "Lithologic mapping in the Mountain Pass area, California using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data", *Remote. Sens. Environ.* vol. 84, no. 3, pp. 350–366. 2003.

[30] K. Shankar, S. Aravindan and S. Rajendran, "Hydrogeochemistry of the Paravanar River Sub - basin, Cuddalore District, Tamil Nadu", *E-Journal of Chemistry*, vol. 8, no. 2, pp. 835-845, 2011.

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