Leak Detection from the Buried Water Transmission Pipeline Using Landsat 8 Satellite Images (Case Study of the Kosar Water…

3 authors:


Roohollah Zanganeh
Iran University of Science and Technology


Barat Mojaradi
Iran University of Science and Technology


Ebrahim Jabbari
Iran University of Science and Technology

International Conference on
Civil Engineering
کنفرانس بین المللی مهندسی عمران

Leak Detection from the Buried Water Transmission Pipeline Using Landsat 8 Satellite Images (Case Study of the Kosar Water Transmission Pipeline)

Roohollah Zanganeh[1,*] -Barat Mojaradi[2]- Ebrahim Jabbari[3]
[1] PhD Candidate, Civil Engineering Department, Iran University of Science and Technology, Tehran, Iran.
[2] Assistant Professor, Civil Engineering Department, Iran University of Science and Technology, Tehran, Iran.
[3] Associate Professor, Civil Engineering Department, Iran University of Science and Technology, Tehran, Iran.
*Corresponding author, Email: roohollah.zanganeh@gmail.com

ABSTRACT

There are various kinds of methods and techniques for water leakage detection from buried aqueducts. Most of them are costly and time consuming while Water companies need to identify leakage quicker than conventional approaches with lower cost and also cover larger areas. In the present study, the possibility of locating water leakages was evaluated in the study area using satellite remotely sensed data. To detect pipeline leakage, the Landsat 8 satellite image processing such as producing a normalized difference vegetation indices (NDVI) map and an NDVI-based classification were used. In addition, the analysis of soil moisture enabled known leaks to be highlighted and differentiated from their immediate surroundings. The outcomes emphasize the contribution of remote sensing techniques to the early detection of leakages by such free medium spatial resolution satellite images. These techniques are easy to be implemented for wide coverage area, especially in the studied area.

Keywords: water pipeline leakage, remote sensing, NDVI, soil moisture, Landsat 8.

1. INTRODUCTION

As water shortage and scarcity exist in many areas of the world nowadays, water leakage, as a significant kind of the physical loss of water, and its detection have become a major problem [1] to [3]. Factors such as soil type, water quality, technology and materials used in a network construction, operating pressure, the age of the system and the operation and maintenance practices can be effective in causing leaks as well as their quantities and intensities [4, 2]. A leak in the main water transmission pipeline usually leads to a large amount of water loss and results in economic losses, customer inconvenience and associated environmental impacts. This reveals the needs for quick and cost effective methods and techniques of leak detection.

Traditional field survey methods for the detection of water pipeline leakages are costly and time-consuming [5]. Conventional techniques used to detect water pipeline leakage include acoustics, radioactive, electromagnetic, Ground Penetrating Radar and Linear Polarization Resistance [6] to [11]. Remote sensing has been used widely for several applications regarding water and vegetation and can be used as a tool for the quick and cost effective detection of leaks [12]. Since the buried pipeline leakage effects are observable on the ground surface in small areas along the pipeline, the main limitation of satellite images is the spatial resolution.

Water leakage from an aqueduct may take many forms, which has implications for the type of surface feature to be detected. In typical mid-summer conditions, leaks at the ground surface should generally be visible as patches of greater soil moisture and/or a change in vegetation biomass, either as increased vegetation growth or, if water logging persists beyond critical tolerance levels, the crop may become stressed and reduce productivity [13]. Soil temperature may also be expected to be reduced.

Vegetation indices (VIs) are mathematical equations of the main spectral data in the red and very near infrared part of the electromagnetic portions which are sensitive to the vegetation behavior. As Agapiou, A. et al. stated [14], VIs can be divided into five main categories according to their formula (equations) or the aim of use of each index: broadband indices, narrowband indices (hyperspectral), leaf pigment indices, stress indices and water stress indices. The normalized difference vegetation index (NDVI) is one of the most successful and well-known of VIs to simply and quickly identify vegetated areas and their "condition" in multispectral remote sensing data. The beneficial use of vegetation indices such as NDVI in other applications such as pipeline leakage detection (e.g. [1,12, 15, 16]) shows the tremendous potentials of using satellite remote sensing for the systematic monitoring of the human and built environment.

Several researches have examined the capabilities of remote sensing for the detection of water leakages. Pickerill and Malthus discussed preliminary results from an investigation into the feasibility of airborne remote sensing techniques for detecting leaks from Vyrnwy Aqueduct [17]. They analyzed two known leaks and found that different vegetation indices and spectral bands were required in order to identify each leak.

Faidrullah used Normalized Different Vegetation Index for Water Pipeline Leakage Detection by remote sensing techniques [12]. He produced NDVI through the SPOT5 image for multispectral and panchromatic modes (2.5-10 meter spatial resolution) in the study area and checked its accuracy with a spectroradiometer and the RMSE analysis. The result shows, the RMSE between the NDVI derived from SPOT5 and the NDVI from the spectroradiometer reflectance gives a small error of 0.1. In his study, 10-meter distance was used as the buffering zone according to the minimum 3 meters suggested by JPBD, [18], to analyze the pipeline leakage detection. In this research ENVI 4.3, ArcView 3.3 and ArcGIS 9.1 software was used to analyze data. He concluded that image processing such as the NDVI technique can help as an indicator to monitor and detect water pipeline leakage from time to time.

Huang et al., in the Lower Rio Grande Valley in Texas, used airborne multispectral remote sensing imagery with high-resolution imaging sensors in the visible, NIR and thermal infrared wavelengths [19]. It was concluded that airborne multispectral imaging is very promising as a tool in the detection of irrigation canal leakage in distribution networks. The images from individual bands, particularly from the thermal band, can help characterize leakage in irrigation canals.

Agapiou et al. exploited remote sensing techniques for the detection of two known water leakages throughout the 25 km length of the pipeline in semiarid areas of Cyprus [4]. In addition, a ground spectroradiometer has been used to define the leakage's threshold values. In their research, two kinds of satellite image, namely the high resolution QuickBird image and the SPOT images were used. In both studies, the NDVI was applied. Based on the available data, two alternative methodologies have been applied using either single high resolution or multi-temporal satellite images. Earlier in another research, Agapiou et al., [1], had evaluated vegetation indices (NDVI, RVI and SAVI) based on the Landsat 7 ETM+ (30 m pixel size) multispectral images in a multi-temporal mode. They showed the use of these VIs and concluded that moisture affects the reflectance of the soil. There is a notable decrease in reflectance with increasing moisture in the ground. It is notable that in most of the researches, the spatial resolution is an important factor relative to the study area for identifying pipe leakage with remote sensing techniques.

In this paper, the detection possibility of three known leakages in the Kosar water transmission pipeline is evaluated using the Landsat 8 satellite images. Indeed, this study probes the possibility of implementing remote sensing techniques in the study area. To this aim, the NDVI image derived from a single satellite image and the NDVI classification image are used. Also, the spectral signature of leakage points compared to their immediate surroundings and a multi-temporal analysis of NDVI of leakage points during 6 dates is surveyed.

2. MATERIAL AND METHODS

2.1. Case Study Area

As shown in Figure 1, the Kosar water transmission pipeline has the duty of water supply to the cities located in the Southwest of Iran in the vicinity of Persian Gulf such as Gachsaran, Behbahan, Boshehr and etc. This pipeline runs from the Kosar dam placed in the Kohkiloye and Boyerahmad province to the beginning of the Moharam pipeline. The existing pipeline with a 1400 to 1800 mm diameter, which passes through the Khozestan and Bosher provinces, too, has made up of three parts with lengths of 78313, 67500 and 65377 m. Steel and cast iron are the materials employed to build this pipeline which has located 1-4 meters below the ground surface. This pipeline, which most of it has placed in a semiarid area, plays an important role in the water supply of the area by approximately passing 4 m3/s. There are also several water treatment plants, reservoirs, pumping stations, valves and branches along the pipeline. It should be noted that leaks are currently detected using ground survey and a continuously recording flow telemetry system in the mentioned pipeline. For example, three major leakages were observed in different sections of the pipe using these approaches in Nov 06, 2014 (see point 1, 2 and 3 in Figure 2).

2.2. Satellite Image and Ancillary Data

The Landsat 8 satellite images the entire Earth every 16 days in an 8-day offset from Landsat 7. Landsat 8 has 11 bands, OLI multispectral bands 1-7 and 9 (30-m pixel size), OLI panchromatic band 8 (15-m pixel size) and thermal infrared (TIRS) bands 10-11. Landsat numbers its red, green, and blue bands as 4, 3, and 2, so when we combine them we get a true-color image.

This study was carried out using Landsat 8 images (such as the image of Nov 06, 2014) for multispectral and panchromatic modes (Figure 2). The date of images has been selected according to leakage information mentioned in Sec. 3. The study area has located in Zone 39 N based on the UTM projection system and satellite path 164 and row 39. Georeferenced vector data of the water transmission pipeline were used as ancillary data. ENVI 5.1 was used to perform

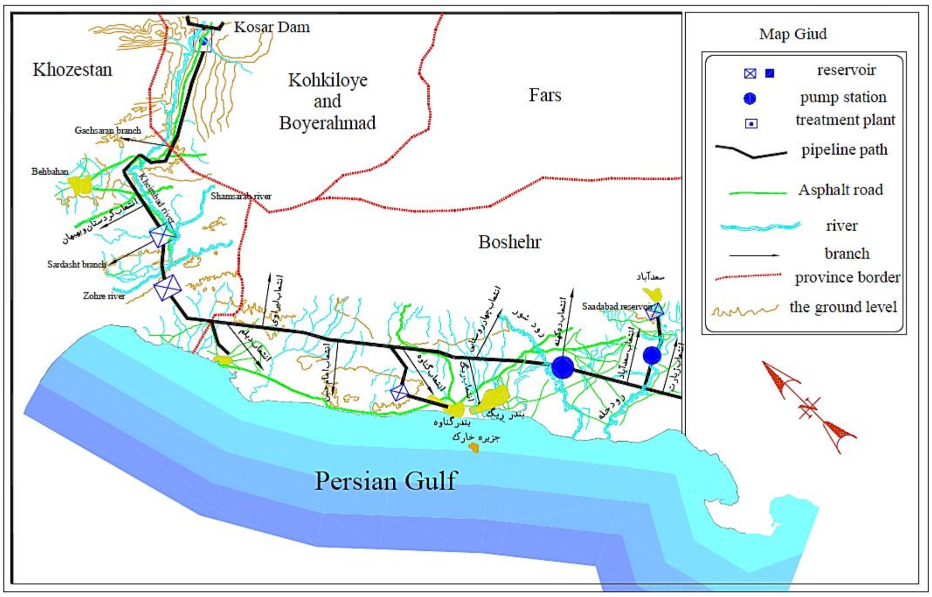


Fig. 1. *Study area.*

the entire preprocessing and processing of satellite images and ArcGIS 10.1 was used for georeferencing the vector data of the pipeline path.

2.3 Methodology

The methodology is based on the use of a single medium resolution image and additional multi-temporal analysis of satellite images for detection of water leakages. The proposed methods are applied in the case study. In general, the steps followed are as follows:

- Step 1: Image acquisition according to the pipeline area.
- Step 2: Image preprocessing for better feature extraction or interpretation.
- Step 3: Georeferencing vector data of the pipeline path in order to determine the accurate position of the pipeline on the preprocessed satellite image.
- Step 4: Processing of the imaging data
- Step 5: Image analysis to identify suspicious leak points
- Step 6: Field reconnaissance to verify image analysis results

As in this study, the georeferenced Landsat 8 image is used; just the vector data of the aqueduct path need to be geometrically corrected so that it can be accurately determined on the satellite image. In the following, steps 2, 4, 5 which formed the main structure of the methodology are explained in more details.

2.3.1 Image preprocessing

As can be seen in Figure 2(a), the main satellite image is larger than the pipeline area. So processing this image takes a lot of computer memory and time. Therefore, the first step in preprocessing is to create a buffer zone around the pipeline path. Radiometric corrections including the atmospheric correction, image fusion (Pan sharpened image, see Figure 2c) to obtain a high spatial resolution multispectral image through the combination of the multispectral image (low spatial resolution) with the panchromatic image (high spatial resolution) and image enhancement are other preprocessing steps that have been applied to the Landsat 8 images. Among the image enhancement techniques, Decorrelation Stretch is defined as the best technique compare to others according to the smallest standard deviation values for each band.

2.3.2 Image Processing

The major step in the image processing is NDVI generation. According to the Landsat 8 spectral specifications, the normalized difference vegetation index (NDVI) image can be generated using the following bands:

$$\text{NDVI}=(R_{NIR} - R_{Red}) / (R_{NIR} + R_{Red}) = (Band\,5 - Band\,4) / (Band\,5 - Band\,4)\ . \qquad (1)$$

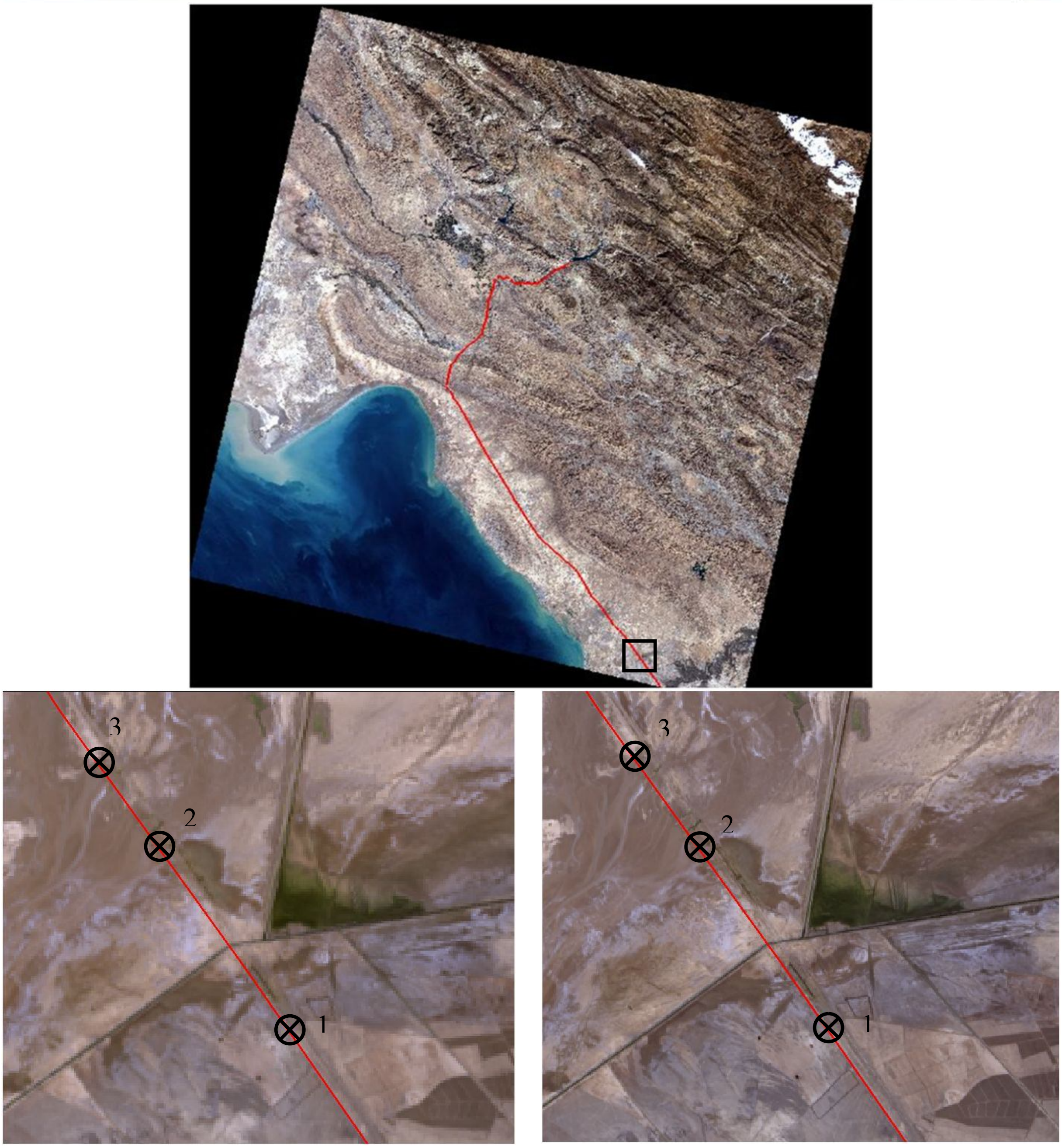


Fig. 2. *(a) top: true-color Landsat 8 satellite image (Nov 06, 2014) over the Kosar water transmission pipeline, (b) left down: true-color image of leakage area (30-m pixel size) and (c) right down: pan sharpened image of leakage area (15-m pixel size).*

Where: RNIR is the reflectance in the near infrared and RRed is the reflectance in the red part of the electromagnetic spectrum.

In this study, instead of applying a threshold to the NDVI image pixel values to determine the areas with possible leakage problems, the technique of unsupervised classification (K-means classification) of the NDVI image by the EVNI software is used.

2.3.3 Image Analysis

In this phase, two approaches are considered. Indeed, this phase is aimed at more precise probing the possibility of existence of the leakage among the suspicious clusters specified in the classification step.

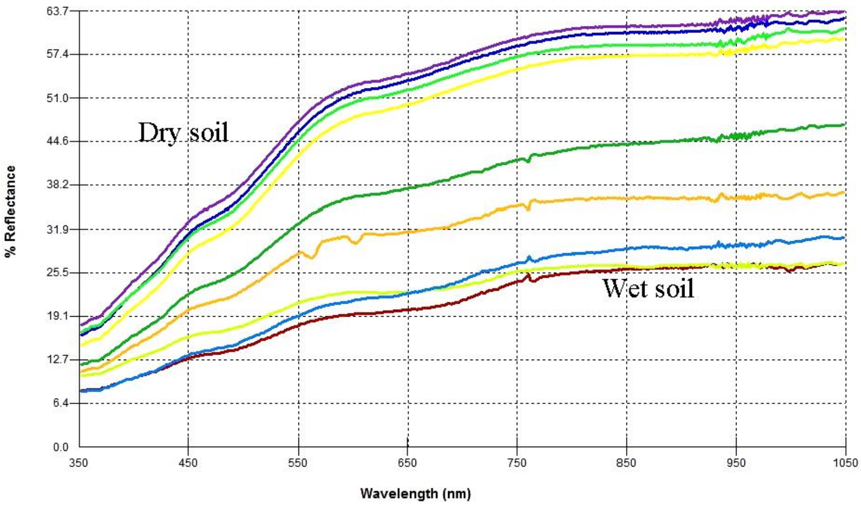


Fig. 3. *Spectral signatures of Dry soil and Wet soil.*

The first approach is based on the soil spectral signature. As shown in Figure 3, the spectral signatures of dry and wet soil are easily differentiated in the visible (400-700 nm) and in the very near infrared (750-900nm) spectral ranges. Indeed, the wet soil tends to give up to 20-25% lower reflectance values compared to the dry soil, with the difference being maximized in the very near infrared range of the spectrum [20,21].

The second approach is based on a multi-temporal analysis of NDVI at the suspicious points. During leakage, at the leakage points and their near surrounding area, the NDVI image pixel values must increase due to the growth of the grass in the fertile soil or decrease due to the soil moisture in the semiarid soil compared to the NDVI image pixel values before the leakage and after rectifying it at the same place.

3. RESULTS AND DISCUSSION

In Nov 05, 2014, a comprehensive field survey and inspection was done by the operational corporate of this pipeline in order to detect the pipeline leakages. After spending so much time and cost, three leakages were identified. Further details of these events are presented in table 1. The mentioned Kilometer values in the second column of this table have been calculated from the beginning of the pipeline, Kosar dam. It is notable that these leakages occurred in the semiarid and partly flat area as can be seen in Figure 2. The amount of leakage in point 1 is much more than the leakage in points 2 and 3; consequently, its effects on the ground surface are more remarkable than the other two points.

The aim of this research is evaluating the possibility of identifying these three leakages by using the presented methodology and the Landsat 8 satellite images. Six medium resolution Landsat 8 OLI images were selected based on the leakage and pipe fixing dates (see table 2). It should be mentioned that image 4 was used as the main image because it is related to the leakage time. Other images were used for final evaluation and multi-temporal analysis of the NDVI image of the leakage points.

Table 1. *The leakages information of Kosar water transmission pipeline.*

Point	Position	Date of pipe fixing	Leakage value (Lit/s)
Point 1	Km 188.600	Nov 09, 2014	2
Point 2	Km 186.206	Nov 09, 2014	0.4
Point 3	Km 185.174	Nov 09, 2014	0.3

Table 2. *Landsat 8 (OLI) Satellite images used in this study.*

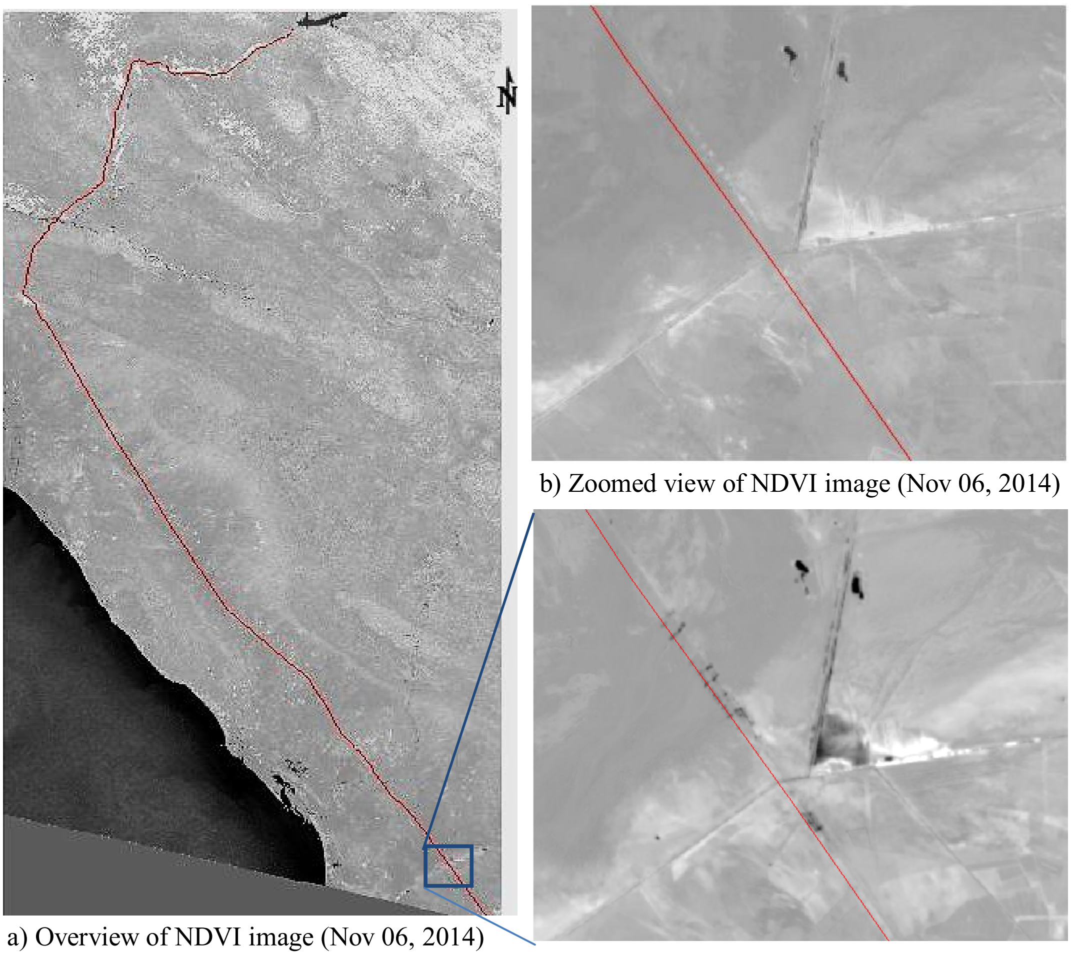
No.	Satellite	Imagery date	No.	Satellite	Imagery date
1	Landsat 8	Aug 18, 2014	4	Landsat 8	Nov 06, 2014
2	Landsat 8	Sep 19, 2014	5	Landsat 8	Dec 08, 2014
3	Landsat 8	Oct 05, 2014	6	Landsat 8	Jan 09, 2015

After the necessary pre-processing steps, the NDVI images were generated. In Figure 4, the NDVI image of the leakage area in Nov 06, 2014 (during the leakage) and Dec 08, 2014 (one month after the pipeline repair) are shown. The NDVI itself varies between -1.0 and +1.0. Negative values of NDVI (values approaching -1) correspond to water (dark pixels). Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, wet soil or snow. Lastly, low, positive values represent dry soil (approximately 0.1 to 0.2) or shrub and grassland (approximately 0.2 to 0.4), while high values (values approaching 1 shown as white pixels) indicate temperate and tropical rainforests [12,14].

As can be seen in Figure 4b (related to leakage time, Nov 06, 2014) compared to Figure 4c (related to one month after leak repair, Dec 08, 2014), several suspicious points have been revealed along the pipe at the considered area. In order to determine the leakage points more accurately, the K-means classification technique (unsupervised classification) is used. The NDVI image of Nov 06, 2014 is divided into 5 classes (see Figure 5). The class with green color has been assigned to values of NDVI between -0.099 ~ 0.089, which has appropriately featured the three known leakage points along the pipeline. In the meantime, other paths of the pipeline were investigated and any other suspicions points were not observed.

Figure 6 presents a multi-temporal NDVI analysis in leakage point 1 during the examined 6 dates of satellite images mentioned in table 2.It is notable that leakage in the pipeline usually leads to the growth of wet grass (Significant increase in the NDVI index) in fertile soil or just the rise of the soil moisture (Significant decrease in the NDVI index) in infertile soil. As can be seen in Figure 6, in this study area, the NDVI values have decreased during the leakage (date 4 means Nov 06, 2014) compared to other dates. It is due to the soil moisture caused by leakage in the semiarid area. After fixing the leakage, the NDVI value approaches almost to its normal range. Also, the soil moisture of leakage points can be identified using the spectral signature of the leakage area compared to its immediate surrounding (see Figure 7). This figure can further improve the results and be reassurance that the cause of the soil moisture is not due to the rainfall and isolate the "suspicious" areas. This investigation was also applied to two other leakages and obtained similar results.

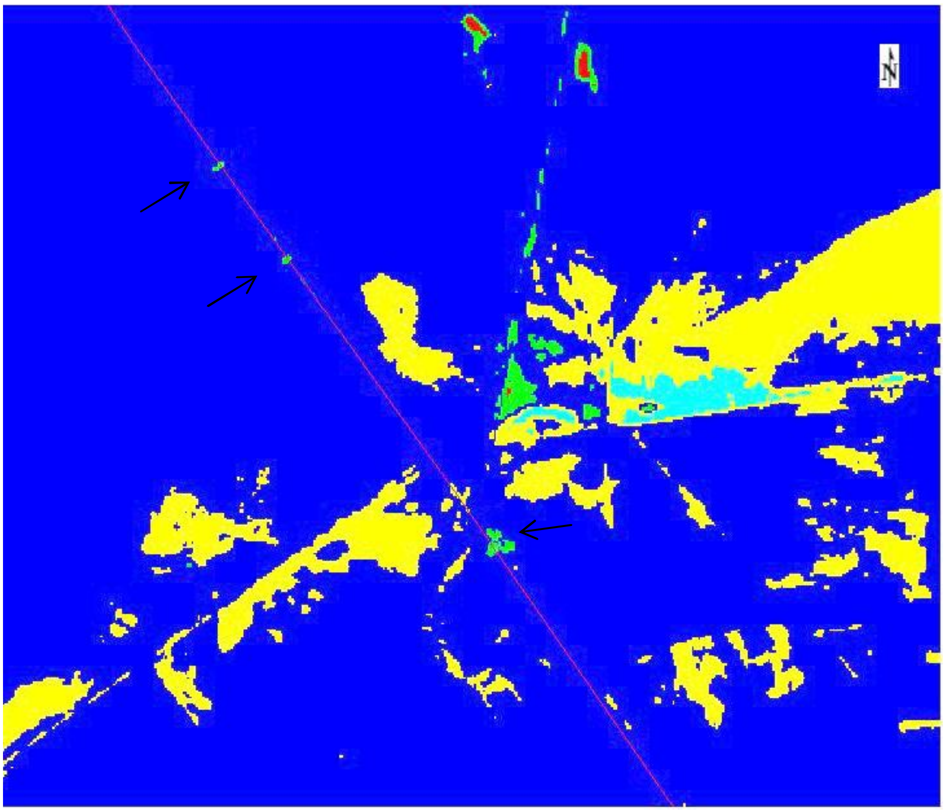
c) Zoomed view of NDVI image (Dec 08, 2014)



b) Zoomed view of NDVI image (Nov 06, 2014)

a) Overview of NDVI image (Nov 06, 2014)

Fig. 4. *NDVI image of pipeline area.*



Classes	Class 1(red)	Class 2 (green)	Class 3 (blue)	Class 4 (yellow)	Class 5 (light blue)
NDVI rang	-0.403 ~ -0.100	-0.099 ~ 0.089	0.09 ~ 0.189	0.191 ~ 0.372	0.374 ~ 0.561

Fig. 5. *Unsupervised classification on the NDVI derived from Landsat 8 image.*

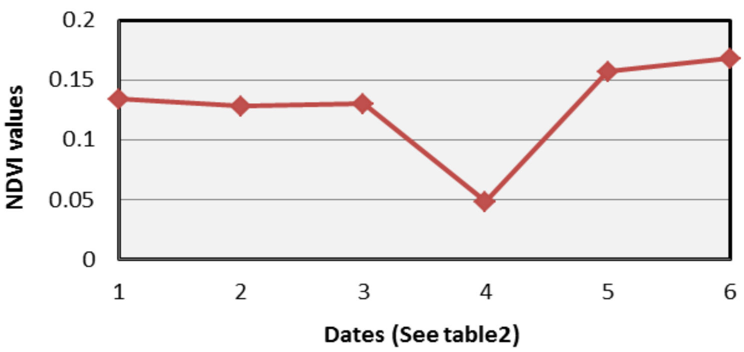


Fig. 6. *NDVI values in leakage point 1 during the examined 6 dates mentioned in table 2 (Landsat images).*

4. CONCLUSION

Satellite remote sensing techniques could provide rapid and synoptic (large area and opportunistic) coverage for leak detection in aqueducts. It has been proven that image processing such as the NDVI technique can help as an indicator to monitor and detect water pipeline leakage repeatedly. It also offers a great advantage to responsible persons or organizations in (a) saving time required to analyze and locate leakage locations and (b) figuring out the leakage in wide areas.

In this research, the production of NDVI from the Landsat 8 image and the classification of the NDVI image for the detection of three known leakages confirm that water leakages from the Kosar aqueduct located in a semiarid area can be recognized using remote sensing techniques. Also, a detailed analysis of the spectral responses and a multi-

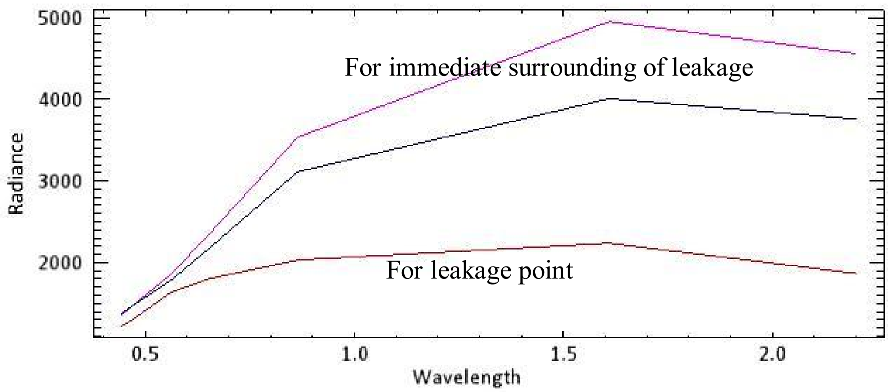


Fig. 7. *Spectral signatures of leakage point 1 (wet soil) compared to its immediate surrounding (dry soil).*

temporal analysis of the detected points in the NDVI image can be applied to distinguish the leakage points from the suspicious points.

It is notable that the appropriate weather, the spatial resolution of satellite images, the amount of leakage, study area conditions and the methodology are important parameters in the accurate detection of buried pipeline leakages. As a result of this study, it is important to be a dry period prior to image acquisition in order to maximize the differences between leak areas and their surroundings in the soil moisture and vegetation characteristics.

5. ACKNOWLEDGEMENTS

Thanks are given to national water and wastewater engineering corporation and Boshehr regional water authority for their supports. Also particular thanks are expressed to Eng. Aburturab, Eng. Porebrahim and Eng. Taghavi for providing data and information of the Pipeline and leakages.

REFERENCES

[1] Agapiou, A., Toulios, L., Themistocleous, K., Perdikou, S., Alexakis, D.D., Sarris, A., Toulios, G., Clayton, C., Foinikaridou, H., Manolis, A., and Hadjimitsis, D.G., (2013a). Use of satellite derived vegetation indices for the detection of water pipeline leakages in semiarid areas. *Proceedings of the SPIE, 8795, 879507*.

[2] Morais, C.D. and de Almeida, T.A., (2007). Group decision-making for leakage management strategy of water network. *Resources, Conservation and Recycling*, Vol. 52, no. 2, p. 441–459.

[3] Weifeng, L., Wencui, L., Suoxiang, L., Jing, Z., Ruiping, L., Qiuwen, C., Zhimin, Q., and Jiuhui, Q., (2011). Development of systems for detection, early warning, and control of pipeline leakage in drinking water distribution: A case study. *Journal of Environmental Sciences*, Vol. 23, no. 11, p. 1816–1822.

[4] Agapiou, A., Dimitrios, D.A., Themistocleous, K., Hadjimitsis, D.G., (2014). Water leakage detection using remote sensing, field spectroscopy and GIS in semiarid areas of Cyprus. *Urban Water Journal*, DOI:10.1080/1573062X.2014.975726.

[5] Critchley R. F., and Aikman, D. I., (1994). Aqueduct management planning: Thirlmere, Haweswater and Vyrnwy Aqueducts. *Journal Institution of Water Environmental Management*, Vol. 12, p. 502-513.

[6] Skolnik, M.I., (1990). *Radar Handbook*, New York: McGraw-Hill.

[7] Heathcote, M., Nicholas, D., (1998). Life assessment of large cast iron watermains. *Urban Water Research Association of Australia* (UWRAA), *Research Report*, No. 146.

[8] Hunaidi, O. and Giamou, P., (1998). Ground penetrating radar for detection of leaks in buried plastic water distribution pipes. *Seventh International Conference on Ground Penetrating Radar*, Lawrence, Kansas, USA, 27-30.

[9] Burn, L.S., Davis, P., Desilva, D., Marksjo, B., Tucker, S.N. and Geehman, C.J., (2001). The role of planning models in pipeline rehabilitation. *Proceedings of Plastic Pipes XI*, Munich, Germany.

[10] Eyuboglu, S., Mahdi, H. dan Al-Shukri, H., (2003). Detection of water leaks using ground penetrating radar, *3rd International Conference on Applied Geophysics*, Orlando, Florida.

[11] Hadjimitsis, D.G., Themistocleous K. and. Achilleos C., (2009). Integrated use of GIS, GPS and sensor technology for managing water losses in the water distribution network of the Paphos Municipality in Cyprus, *Proceedings of STATGIS,* Milos, Greece.

[12] Faidrullah N.S., (2007). Normalized different vegetation index for water pipeline leakage detection, *28th Asian Conference on Remote Sensing*, PWTC, Kuala Lumpur, Malaysia.
[13] Steven, M. D., Malthus, T. J., and Clark, J. A., (1992). Achievements and unresolved problems in vegetation monitoring. In *Terra 1: Understanding the terrestrial environment; The role of earth observations from space*, edited by P. M. Mather (London:Taylor and Francis), pp. 133-145.
[14] Agapiou A., Hadjimitsis D.G. and Alexakis, D.D., (2013). Evaluation of broadband and narrowband vegetation indices for the identification of archaeological crop marks. *Remote Sensing*, Vol. 4, no. 12, p. 3892-3919.
[15] Hadjimitsis, D.G., Papadavid, G., Agapiou, A., Themistocleous, K., Retalis, A., Michaelides, S., Chrysoulakis, N., Toulios, L., and Clayton, C.R.I., (2010). Atmospheric correction for satellite remotely sensed data intended for hydrological cycle applications: impact on vegetation indices. *Natural Hazards and Earth System Sciences*, Vol. 10, p. 89–95.
[16] Papadavid, G., Fasoula, D., Hadjimitsis, M., Perdikou, S., and Hadjimitsis, D.G., (2013a). Image based remote sensing method for modeling black-eyed beans (Vigna unguiculata) Leaf Area Index (LAI) and Crop Height (CH) over Cyprus. *Central European Journal of Geoscience*, Vol. 5, no. 1, p. 1–11.
[17] Pickerill, J.M. and Malthus, T.J., (1998). Leaks detection from rural aqueducts using airborne remote sensing techniques. *International Journal of Remote Sensing*, Vol. 19, no. 12, p. 2427–2433.
[18] Jabatan Perancangan Bandar dan Desa Semenanjung Malaysia, (1998). Garis Panduan Perancangan Jalan, Terbitan.
[19] Huang Y., Fipps, G., Maas, S. and Fletcher, R., (2009). Airborne remote sensing for detection of irrigation canal leakage. Irrigation and Drainage, *Published online in Wiley InterScience*, doi: 10.1002/ird.511.
[20] Kaleita, A.L., Tian, L.F. and Hirschi, M.C., (2005). Relationship between soil moisture content and soil surface reflectance. *Transactions of the American Society of Agricultural Engineers*, Vol. 48, no. 5, p.1979-1986.
[21] Rodríguez, J. N., (2011). Changes in spectral slope due to the effect of grain size and moisture in beach sand of western puerto rico. from http://gers.uprm.edu/pdfs/ topico_johanna2.