Role of GIS and Remote Sensing in the Environmental Management of Petroleum/Gas Pipelines

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Abstract

The main goal of this research was to monitor vegetation cover (VC) percentage along Baku-Tbilisi-Ceyhan oil export pipeline in 2007 and 2008 and also VC re-growth rate between two years using high-resolution multispectral satellite images. The research covered area of 44 m wide and 442 km long Baku-Tbilisi-Ceyhan pipeline corridor where VC was disturbed in the process of underground oil pipeline construction. For the achievement of this goal, IKONOS 2007 and FORMOSAT 2008 NDVI were normalized to VC percentage using the regression analysis with in-situ estimated VC percentage for transects. VC re-growth rate was also compared between 2007 and 2008 years. Detailed maps of VC percentage were developed along pipeline corridor. VC percentages were quantified within the predefined classes for the general evaluation of re-growth rates.

1 Introduction

The research was focused on the environmental monitoring of renaturation activities of VC along BTC oil export pipeline in Azerbaijan. The construction of BTC pipeline was completed in 2005. The research covered the part of BTC pipeline corridor passing over the territory of Azerbaijan. The total length of BTC pipeline passing Azerbaijan is 442 km and pipeline corridor width is 44 m.

Azerbaijan is rich with the natural resources of oil and gas (ALIYEV et al. 2006). For the exploration and exploitation of these natural resources it is often applied to the industrial construction activities. For the export of oil resources to Turkey through Georgia, BTC oil pipeline was constructed and in the process of construction VC along pipeline was disturbed by excavation and construction activities. Construction of BTC pipeline was completed in 2005 and after this VC had to be restored to its pre-construction state and pipeline construction footprint had to disappear in accordance with Azerbaijan environmental regulations. There is a global increase in the recognition of environmental, social and economic values of native vegetation, in particular in terms of sustainability and maintenance of natural resources. Land-use changes are among the most important human alterations affecting the ecosystems of the earth since their direct impact is negatively expressed on biological diversity, local and regional climate changes and also on global climate warning (SULIEMAN 2008). Land degradation is the deterioration in quality of land brought by human activity without due care (AYOUB 1999). Passive restoration means allowing natural processes to return to a stream by stopping activities that cause

degradation or prevent recovery (KAUFFMAN et al. 1997). This way of restoration does not require real financial support and they are likely to be self-sustaining because they originate from nature (SULIEMAN 2008). Furthermore, the natural restoration process is very important to enhance the biological diversity of the landscape (YIRDAW 2002). The natural process can achieve full restoration but some time it may take a long time and need to be assisted (BRADSHAW 1996; YIRDAW 2002; DUNCAN et al. 1999). In case with the BTC pipeline, it was required by environmental regulations to start renaturation activities as soon as pipeline construction was completed in 2005 and it was applied to active methods of restorations like sawing and seeding activities along pipeline corridor. For this research, it was applied to high resolution multi-spectral IKONOS 2007 and FORMOSAT 2008 satellite images to develop spatial grids of VC from NDVI spatial grids extracted from these images applying also to the ground truth data and to conduct re-growth analysis between these two years. This methodology is restricted to be applied for non-agricultural areas since these lands are not affected by anthropogenic activities.
The first peculiarity of this research is that it deals with quite a detailed scale of territory and that's a reason why it was applied to high resolution and accuracy multi-spectral satellite images. The second peculiarity of this research is that it allowed determining regression coefficients of NDVI to VC percentage for different satellite data sources. The third peculiarity of this research is that it deals with a quite detailed scale of territory and requires considering preliminary remote sensing corrections to avoid of significant discrepancies in the final results. The forth peculiarity is that it can be applied as a practical collaborative environmental management system for renaturation activities (BAYRAMOV et al. 2008).

2 Study Area

The research area is BTC pipeline which starts in Azerbaijan from Sangachal Terminal on the coast of the Caspian Sea and passes through Georgia and Turkey territory and it ends at Turkey Ceyhan Marine Terminal where from oil is exported through Mediterranean Sea. Total length of the pipeline passing through Azerbaijan is 442 km and it is presented in figure 1(a). Oil exploration is being conducted in the Caspian Sea and a total of 10 million barrels of oil from Azeri-Chirag-Gunashli oil fields in Azerbaijani sector of the Caspian Sea was required to fill pipeline (AETC 2001; BAYRAMOV et al. 2009). The buffer zone of 22 m to both sides of buried BTC pipeline is named On-Right-of-Way (On-RoW) and areas outside of pipeline 44 m corridor are named Off-Right-of-Way (Off-RoW). VC was disturbed along On-RoW during excavation and construction works and renaturation activities like seeding and sawing are being implemented inside On-RoW after the completion of pipeline construction (see figure 1(b) -1(d)).

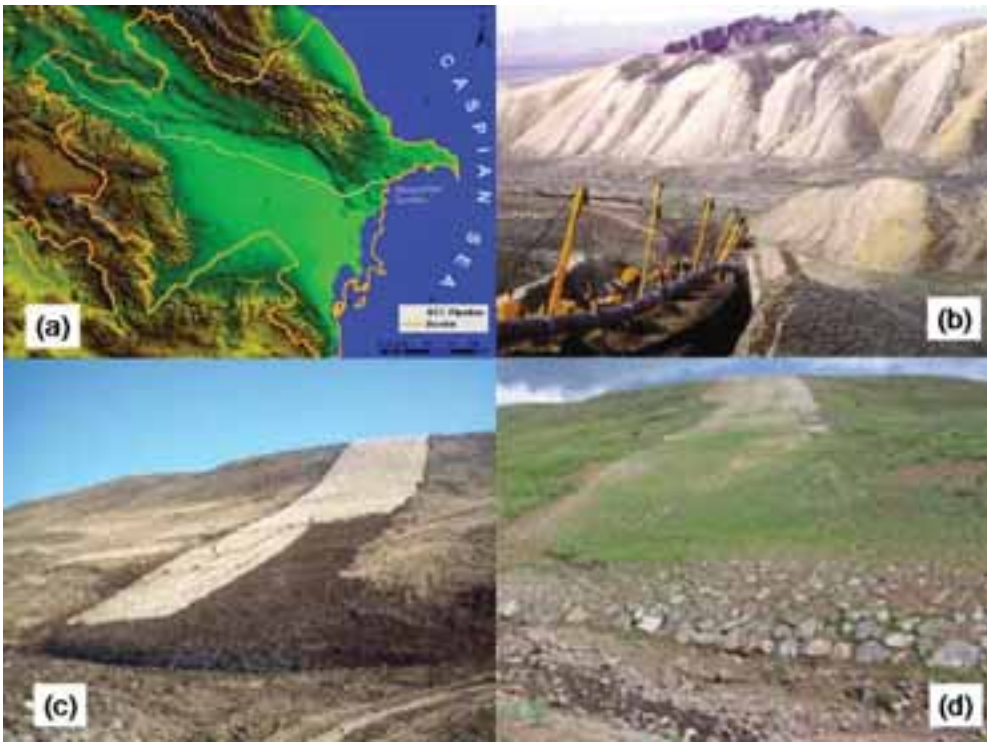

Fig. 1(a) BTC Pipeline (Azerbaijan Area); (b) BTC pipeline construction; (c) sample of pipeline corridor in 2005; (d) sample of pipeline corridor in 2008

3 Materials and Methods

3.1 Theoretical Background

NDVI is not an intrinsic physical quantity, although numerous studies spanning many years have shown a positive and generally linear relationship between NDVI and VC (BECHTEL et al. 1997; HUETE et al. 1994; LEPRIEUR et al. 2000). This observation forms the basis of the null hypothesis which is that NDVI is unrelated to VC (LEPRIEUR et al. 2000). The strength of the observed relationship between NDVI and VC has been shown to be influenced by a variety of biophysical factors such as plant structure, background soil reflectance, shadow effects, solar and viewing angle, and atmospheric effects (BECHTEL et al. 1997; HUETE et al. 1994; LEPRIEUR et al. 2000). These factors vary locally, and hence there is a need for auxiliary ground truth information to NDVI extracted from the satellite data to measure the strength of the correlation in different VC habitats and to recalculate NDVI to VC (CARLSON et al. 1997).

3.2 Remotely sensed data

IKONOS and FORMOSAT high resolution multispectral satellite images were acquired along BTC pipeline corridor in 2007 and 2008, respectively. They were acquired in

accordance with the dates of vegetation peak (April - July) along BTC pipeline corridor. Coverage of IKONOS and FORMOSAT satellite images along with dates of acquisition is presented in figure 2(a) and figure 2(b), respectively. The IKONOS and FORMOSAT satellite sensor characteristics are presented in table 1.

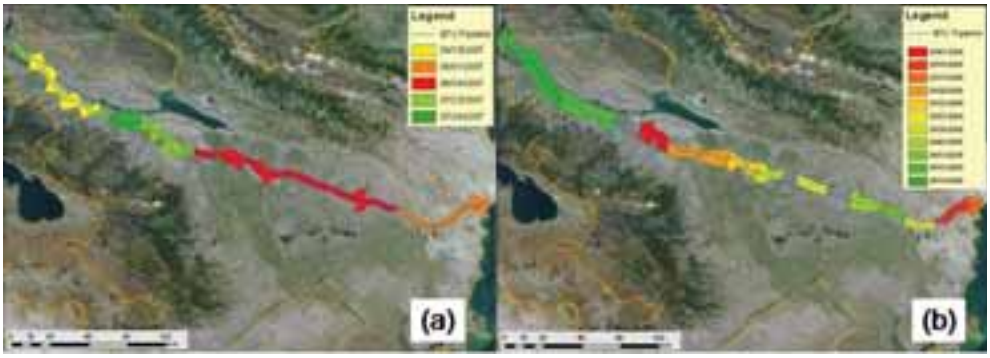

Fig. 2 (a) IKONOS satellite images acquired in 2007 along BTC pipeline; (b) FORMOSAT satellite images acquired in 2008 along BTC pipeline

Table 1: Characteristics of IKONOS and FORMOSAT of satellite sensor

CHARACTERISTICS OF SATELLITE SENSOR		
Launch Date	IKONOS	September , 1999
	FORMOSAT	May, 2004
Spectral Bands	IKONOS	Pan: 0.45 - 0.90 µm; Blue: 0.45 - 0.53 µm; Green: 0.52 - 0.61µm Red: 0.64 - 0.72µm; Near-infrared: 0.77 - 0.88 µm
	FORMOSAT	Pan: 0.45 - 0.90 µm; Blue: 0.45 - 0.52 µm; Green: 0.52 - 0.60 µm; Red: 0.63 - 0.69 µm; Near-infrared: 0.76 - 0.90 µm
Spatial resolution	IKONOS	B&W: 1 meter, Multispectral (R, G, B, NIR): 4 meter
	FORMOSAT	B&W: 2 meter , Multispectral (R, G, B, NIR): 8 meter
Swath Width	IKONOS	11 km x 11 km
	FORMOSAT	24km x 24km
Orbit Altitude	IKONOS	681 km
	FORMOSAT	891 km
Orbit Inclination	IKONOS	98.1 degrees, sun-synchronous
	FORMOSAT	99.1 degrees
Speed	IKONOS	7 km/second
	FORMOSAT	7.2km per second
Revisit Time	IKONOS	1.5-3 days depending on latitude
	FORMOSAT	Daily
Image Dynamics	IKONOS	11 bits
	FORMOSAT	8 bits
Original Metric Accuracy (Horizontal)	IKONOS	12 m horizontal (RMSE)
	FORMOSAT	50 m horizontal (RMSE)

3.3 Applied methodology

The methodology stages of the complete process for the achievement of results are presented in figure 3. The following basic stages were used: improvement of geometric and positional accuracy of satellite images, development of accurate VC by normalization of NDVI using ground-reference data of transects through the regression analysis, mapping of VC percentage, determination of the overall statistics of VC percentage distribution.

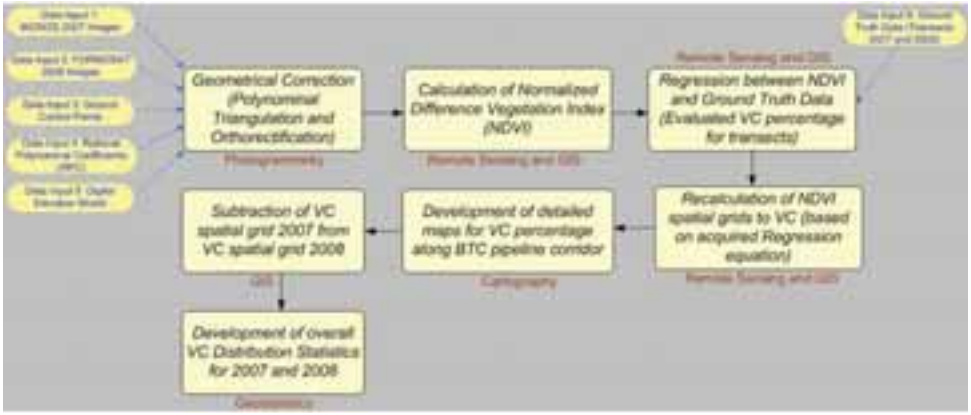

Fig. 3: Sequence of methodological stages and input data

NDVI is an index derived from satellite reflectance data that measures 'greenness' of vegetation, a proxy for chlorophyll levels in a plant (BECHTEL et al. 1997; HUETE et al. 1994; LEPRIEUR et al. 2000). NDVI has been widely used in describing relationships between vegetation characteristics such as above-ground biomass, green biomass and chlorophyll content (TUCKER 1985). PUREVDORJ et al. (1998) estimated the percentage of the VC from vegetation indices using simulated AVHRR data derived from in situ spectral reflectance data and it was found that transformed soil – adjusted vegetation index and NDVI gave the best estimates of the VC for a wide range of grass densities (SULIEMAN 2008). The satellite data was processed to generate NDVI that essentially allows areas covered by vegetation to be distinguished from bare ground, and was derived from the following equation: NDVI = (Band 4 (Near Infra Red) – Band 3 (Red)) / (Band 4 (Near Infra Red) + Band 3(Red)).

Ground truth data were field-collected transect data with the evaluated VC percentage for 2007 and 2008. Spatial location of transects was measured by high-precision GPS with the accuracy of 1 m. VC percentage was evaluated for transects with disturbed (On-RoW) and non – disturbed (Off-RoW) areas along BTC pipeline corridor. Field evaluation of VC percentage involved the use of quadrate with the size of 1m x 1m and with a minimum sampling of 8 quadrates per transect where 5 is for On-RoW and 3 is for Off-RoW areas of transect (see figure 4(a)). At each quadrate, VC was assessed by determining the relative proportion of bare ground to vegetation that can be observed looking vertically onto the quadrate (see figure 4(b)). To the extent possible, the collection of field data for ground truthing purposes should occur within the time planned for acquisition of images. Optimum timing of satellite data acquisition specific for Azerbaijan VC is April - July.

Fig. 4: (a) Sample of transects along Off-RoW and On-RoW of BTC pipeline; (b) Sample transects along BTC and quadrate way of assessment

Regression analysis was used to understand the relationship between NDVI and in-situ estimated percentage of VC. This allowed NDVI values to be calibrated against field measurements of VC, i.e, for a given NDVI value, a corresponding VC percentage value is determined via the derived regression equation. Regression analysis were conducted separately for transects within non-forest and forest habitats since transects shapes and sizes differed in both of these habitat types. After acquisition of regression equations for forest and non-forest habitats of 2007 and 2008, NDVI spatial grids for both 2007 and 2008 correspondingly were recalculated to VC. This stage was necessary for the development of maps which depicts VC at 10 % intervals. Generation of accurate VC maps represents the first step in developing conservation and management plans for natural resources (SULIEMAN et al. 2007). Based on the recalculated NDVI to VC, the distribution of VC percentage was quantified for comparative purposes.

4 Results

4.1 Developed NDVI and collected ground truth data with estimated VC

NDVI spatial grids extracted from each image of IKONOS 2007 and FORMOSAT 2008 are presented in figure 5(a) and figure 5(b). As a result of the collection of transects along BTC pipeline in 2007 and 2008, 53 transects were measured. Each transect consisted of transects with measured VC percentage for On-RoW and Off-RoW areas and this means that total number of transect polygons was 106 for On-RoW and adjacent Off-RoW pipeline areas. Spatial distribution pattern of collected transects is presented in figure 5(c).

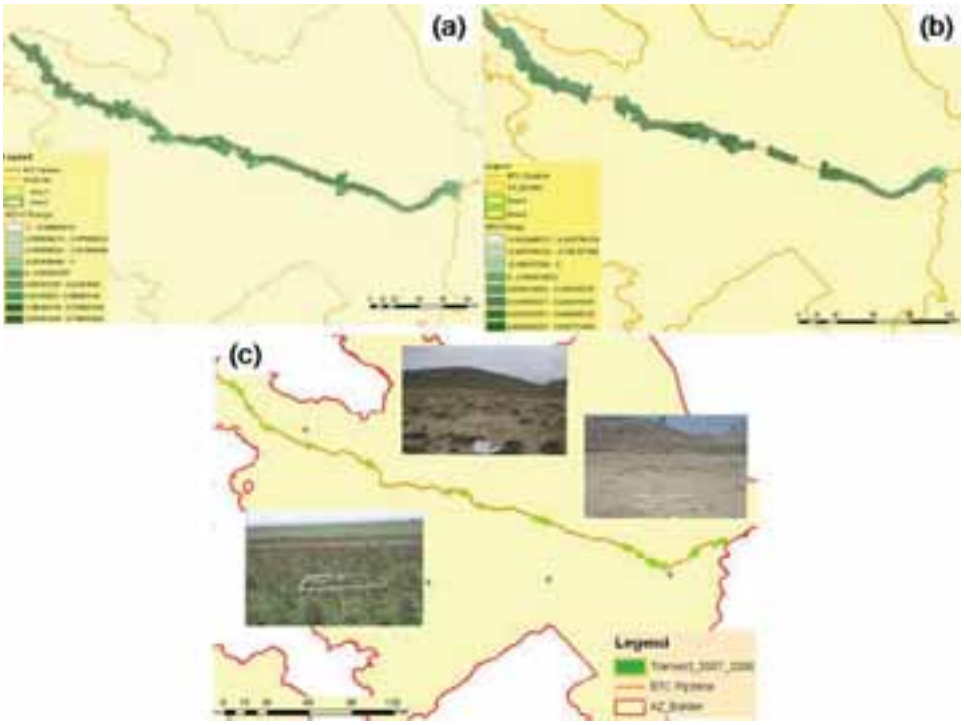

Fig. 5: NDVI Spatial Grids calculated from (a) IKONOS images 2007; (b) FORMOSAT images 2008; (c) Spatial distribution patterns of transects collected in 2007 and 2008

4.2 Regression analysis between NDVI and VC percentage values for 2007 and 2008 years

As a result of regression analysis between average IKONOS 2007 and FORMOSAT 2008 NDVI values and field-estimated VC percentage for each transect polygon, it was possible to achieve regression equations necessary for the normalization of NDVI to VC percentage. Regression analysis between NDVI and VC for non-forest and forest transects are presented in figure 6(a)-6(d).

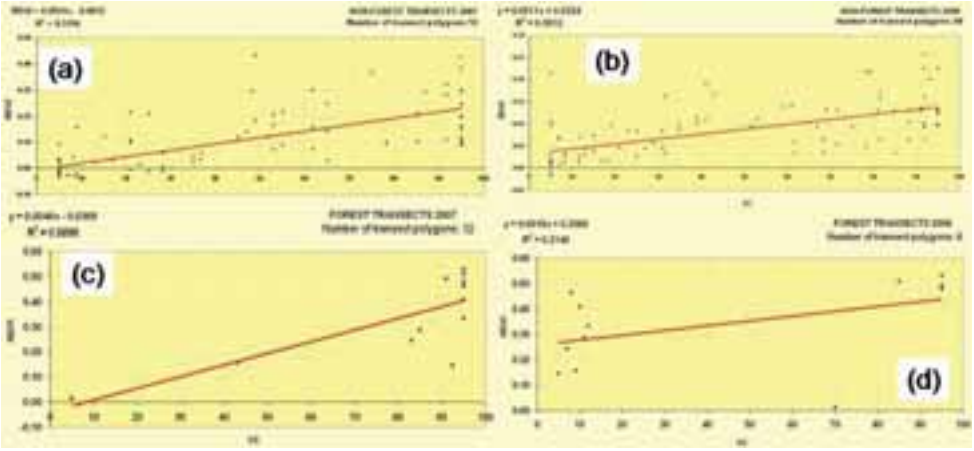

Fig. 6: Regression between Transects' NDVI and for these transects (a) between non-forest habitat for IKONOS and field measured VC of 2007; (b) between non-forest habitat for FORMOSAT and field measured VC of 2008; (c) between forest habitat for IKONOS and field measured VC of 2007; (d) between forest habitat for FORMOSAT and field measured VC of 2008; along pipeline route

4.3 Developed Maps from VC Spatial Grids

Based on the acquired equations for non-forest and forest habitats, NDVI spatial grids 2007 (IKONOS) and NDVI spatial grids 2008 (FORMOSAT) of pipeline route were normalized to VC 2007 and 2008. Normalization was achieved for the entire pipeline route and two sample areas with VC percentage are presented in figure 7(a) and figure 7(b) for VC 2007 and in figure 7(c) and figure 7(d) for VC 2008. Normalization allowed to change the NDVI units to VC percentage and to validate the NDVI 2007 (IKONOS) and NDVI 2008 (FORMOSAT) to ground truth situation using data from field evaluated VC percentage of transects. VC regrowth analysis through overlay analysis of developed 2007 and 2008 vegetation cover spatial grids allowed to determine the potential areas requiring renaturation activities in 2009 along entire BTC pipeline and these areas are presented in figure 7(e).

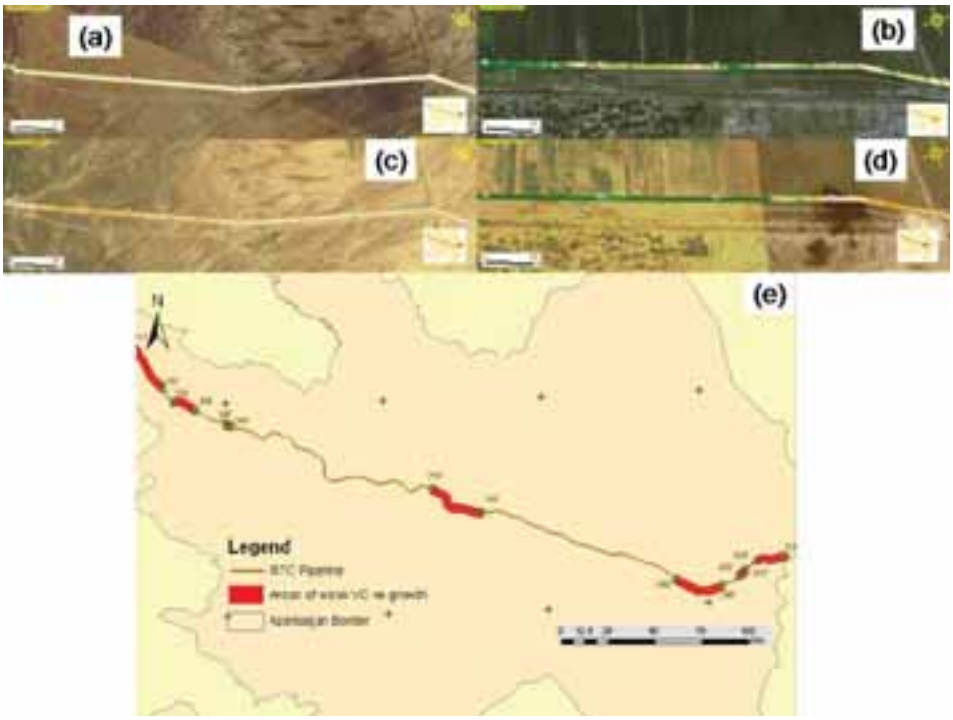

Fig. 7: Developed vegetation cover from (a) NDVI 2007 for sample area 1; (b) NDVI 2008 for sample area 1; (c) NDVI 2007 for sample area 2; (d) NDVI 2008 for sample area 2; (e) Areas of weak vegetation cover re-growth along pipeline with a demand for continuation of revegetation activities in 2009

4.4 Developed Statistics for the distribution of VC Percentage

VC was quantified within VC percentage classes (see figure 8(a), 8(b)). The area of 20-30% VC along pipeline route was 375160 sq. m. in 2007 (see figure 8(a)) but it improved to 421000 sq. m. in 2008 (see figure 8(b)). It is also possible to observe that the area of 0-10% VC percentage class reduced in 2008 since other VC classes increased. (see figure 8(a), 8(b)). 90-100% was 923036 sq. m. in 2007 and it became 990000 sq. m. 2008 what means that some amount of VC from lower VC percentage classes reached 90-100%.

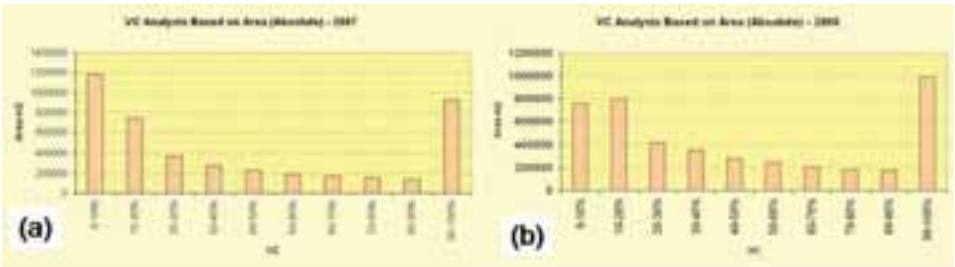

Fig. 8: Percentage of VC distribution (a) in 2007 (b) in 2008 along pipeline corridor

5 Conclusion

This research allowed to assess the renaturation progress between 2007 and 2008 years on the general and detailed levels along Azerbaijan section of BTC pipeline. This research allowed to determine VC percentage and its re-growth using developed NDVI from high resolution multispectral IKONOS 2007 and FORMOSAT 2008 satellite images and in-situ estimated VC percentage. This studies also allowed to determine and validate the regression coefficients and relationship between NDVI and field-estimated VC percentage. This research laid out the base for the determination of areas with negative and positive revegetation results between two years and to plan further areas along BTC pipeline corridor for the continuation of revegetation activities. This GIS- and Remote Sensing-based approach gives possibility for the monitoring of revegetation progress along wide-range petroleum and gas pipelines in Azerbaijan as well as Worldwide.

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