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SOIL SALINITY CHANGE DETECTION IN IRRIGATED AREA UNDER QAZVIN PLAIN IRRIGATION NETWORK USING SATELLITE IMAGERY

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ABSTRACT Qazvin Plain Irrigation Network (QPIN) is one of the first modern irrigation networks constructed in Iran and supplies irrigation water for about 60,000 ha of agricultural area. QPIN is a conjunctive type network with about 28 percent of surface water from Taleghan Dam and remaining supplies from groundwater resources. Groundwater quality is decreasing from over exploitation and it is expected that soil is being salinized gradually. In this research, soil salinity change was detected using satellite images as well as measurement and analysis of soil extract electrical conductivity (ECe). Landsat-TM/ETM+ images of the years 1999 and 2004 were used with more than 130 ground control points of salinity analysis. Relationships between ECe and image bands were investigated. The results showed that soil salinity class varied by an average of about 3 percent on the farmlands under QPIN during these 5 years.

Keywords: Soil Salinity, Satellite Images, Qazvin Plain, Irrigation Network, Landsat-TM/ETM+.

INTRODUCTION Soil salinity caused by natural or human-induced processes is a major environmental hazard. There are extensive areas of salt-affected soils on all the continents, but their extent and distribution have not been studied in detail (Abrol et al., 1988). Statistics relating to the extent of salt-affected areas vary according to authors, but estimates are in general close to 1 billion ha, which is about 7 percent of the earth's continental extent (Wannakomol, 2005). In addition to these naturally salt-affected areas, about 77 million ha have been salinized as a consequence of human activities, and 58 percent of these areas concentrated in irrigated areas (Ghassemi et al., 1995). Nearly 20 percent of all irrigated lands is salt-affected, and this proportion tends to increase in spite of considerable efforts dedicated to land reclamation (Metternicht and Zinck, 2003). This requires careful monitoring of the soil salinity status.

Major parts of the salt-affected areas are placed in Australia, North and Central Asia and South America (Table 1). In Southeast Asia, salt-affected areas cover about 20 million ha or about 2 percent of all salt-affected areas of all the continents. According to the United Nations Economic and Social Commission for Asia and Pacific (UN-ESCAP), salt-affected areas exceed 20 million ha in China, India and Iran (Szabolcs, 1979).

Table 1. Extent of salt-affected soils on all the continents [Szabolcs, 1979].

Region	Salt-affected areas	
	Million of hectares	Percent
Australia	357.3	37.5
North and Central Asia	211.7	22.2
South America	129.2	13.6
South Asia	84.8	8.9
Africa	80.5	8.5
Europe	50.8	5.3
Southeast Asia	20.0	2.1
North America	15.7	1.6
Mexico and Central America	2.0	0.2
Total	952.0	100.0

Saline soils may theoretically occur in any region and every climate in the world. However, these soils are mostly concentrated in semi-arid and arid regions. One of the conditions for the presence or formation of saline soils is evaporation, which greatly exceeds precipitation. During the dry season, evaporation mostly exceeds precipitation, arid and semi-arid regions suffer from a soil moisture deficit, and soil salinity is most widespread. Saline fields are often identified by presence of spotty patches of precipitated salts. Such precipitates usually occur in elevated or non-vegetated areas, where water evaporates and leaves salt behind. Such salt crusts can be detected on satellite images. Remote sensing can provide information for large areas, and in a relatively short time. In addition, remote sensing is not limited by extremes in terrain or hazardous condition. Generally, remote sensing should be integrated into early stages of investigations and be used in conjunction with traditional mapping techniques. There were many attempts to use the remote sensing data and its techniques to detect salt-affected soils. Some of these studies are summarized below:

Menenti et al. (1986) found that Landsat TM (Thematic Mapper) data in band 1 through band 5 and band 7 are good for identifying salt minerals, at least when salt is a dominant soil constituent. Moreover, salt minerals affect the thermal behaviour of the soil surface. Mulders and Epema (1986) produced thematic maps indicating gypsiferous, calcareous and clayey surface using TM band 3, 4 and 5. They found TM data a valuable aid for mapping soil in arid areas when used in conjunction with aerial photographs. Saha et al. (1990) used digital classification of TM data in mapping salt affected and waterlogged land in India, and found that these salt-affected and waterlogged areas could be effectively delineated, mapped and digitally classified with an accuracy of about 96 percent using bands 3, 4, 5 and 7. Dwivedi and Rao (1992) suggested three-band combination of 1-3-5 to separate saline soil on the base of optimum index factor (OIF). Brena et al. (1995) used multiple regression analysis of the electrical conductivity values and spectral observations to estimate the electrical conductivity for each pixel in the field, based on sampling sites in Mexico. They generated a salinity image using the regression equation. Sah et al. (1995) suggested Landsat TM image with bands other than 2 and 6 was found effective to recognize extremely and moderately saline areas. Dwivedi (1996) applied principle component analysis of Landsat-MSS (MultiSpectral Scanning) bands 1, 2, 3 and 4 in delineating salt affected soils. Abdinam (2004) and Taghizadeh Mehrjardi et al. (2008) suggested an exponential function of band 3 and 7 of TM/ETM+ for modeling electrical conductivity of soil extract (ECe). Tripathi, et al. (1997) used two indices, salinity index and normalized difference salinity index to highlight the alkaline zones of the soils of Kanpur, India. They used IRS-1B LISS II bands in their study. Peng (1998) used a false color image of TM bands 4, 3 and 2 to distinguish salinized soil from non-salinized areas. Naseri (1998) suggested that both types of digital classification, unsupervised and supervised, could be used for the proper identification of salinity, mostly at a regional level. MSS bands 3, 4 and 5 are recommended for salt detection in addition to TM bands 3, 4, 5 and 7. Alavipanah et al. (1999) studied soil salinity in Ardakan area, Iran based on the field observations and remotely sensed data. They concluded that behaviour of the TM thermal and reflective bands is highly dependent on the type of land cover.

Fouad (2003) applied ASTER bands 3, 4 and 5 data in terms of a salinity index together with the biophysical method based on detecting the crop reaction to soil salinity via osmotic forces and the increasing surface resistance due to stomatal closure to detect salinity in the irrigated area in the northern part of Syria.

Wannakomol (2005) reviewed several investigations on salinity mapping in Thailand. He combined remotely sensed data by ground observations and geophysical methods to map salt-affected area in Khorat Plateau. He concluded that ASTER image is more effective than Landsat ETM+ data. Douaoui et al. (2006) studied soil salinity in Lower Cheliff Plain, Algeria using remotely sensed salinity indices and ground based measurements of electrical conductivity. They used SPOT XS image in green, red and near infrared bands. Farifteh et al. (2006) developed an algorithm to mapping soil salinity using remote sensing, solute transport modeling and geophysical techniques. Fernandez-Buces et al. (2006) used bands 1 to 4 of Landsat TM images with normalized difference vegetation index (NDVI) to map salinity and alkalinity in Texcoco Lake Region Mexico.

In this study, mapping salt affected soils in Qazvin Plain, north-west of central part of Iran using Landsat ETM+ image has been investigated.

STUDY AREA The Qazvin Plain with its adjacent watersheds has an area of 9,300 km^2. It is located between 49^o 25' to 50^o 35' east longitude and 35^o 25' to 36^o 25' north latitude. Approximate area of Qazvin Plain is about 450,000 ha. A modern irrigation network was constructed to deliver water from Taleghan Regulating Dam for 60,000 ha of irrigated farm lands. Taleghan Dam and its irrigation network deliver water to Qazvin Plain from Taleghan River Basin. In other words, Qazvin Plain Irrigation Network (QPIN) transfers water between two adjacent watersheds. QPIN is a conjunctive type network with about 28 percent of surface water from Taleghan Dam and remaining supplies from groundwater resources. Groundwater quality is decreasing from over exploitation and it is expected that soil is being salinized gradually. Qazvin Plain is a depression which is filled by alluvium with a thickness of about 200 m and forms an unconfined aquifer. General slope of the plain is less than 1 percent. Therefore, natural subsurface drainage is limited and it is concentrated toward eastern part of the plain.So, eastern part of plain is waterlogged and saline. Figure 1, shows Qazvin Plain, irrigation network and irrigated farms, saline area using a RGB=752 of Landsat/TM image of June 28, 1987. Qazvin Province is located within two scenes of 165-035 and 166-035 of mentioned image Daneshkar Arasteh, 2009). Groundwater quality and depth was studied in 1985 and 2006. Figure 2 shows watertable depth contour map for two years. As it is shown, groundwater surface increase from 3 m depth in 1985 to 1 m depth in 2006 for consecutive irrigation practices. Also, top soil extract analysis showed increase in ECe from 1985 to 2006 (Figure 3).

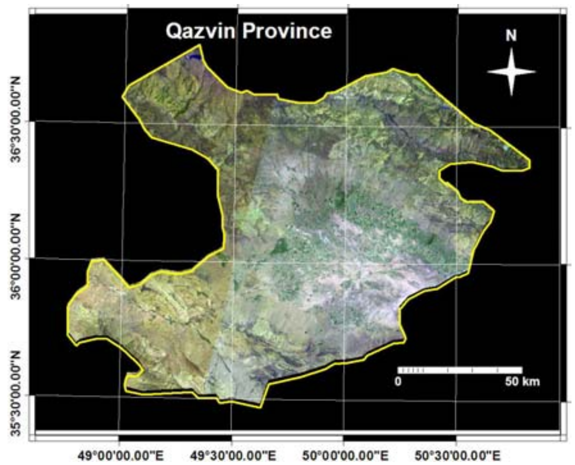

Figure 1. Qazvin Province in north of Iran.

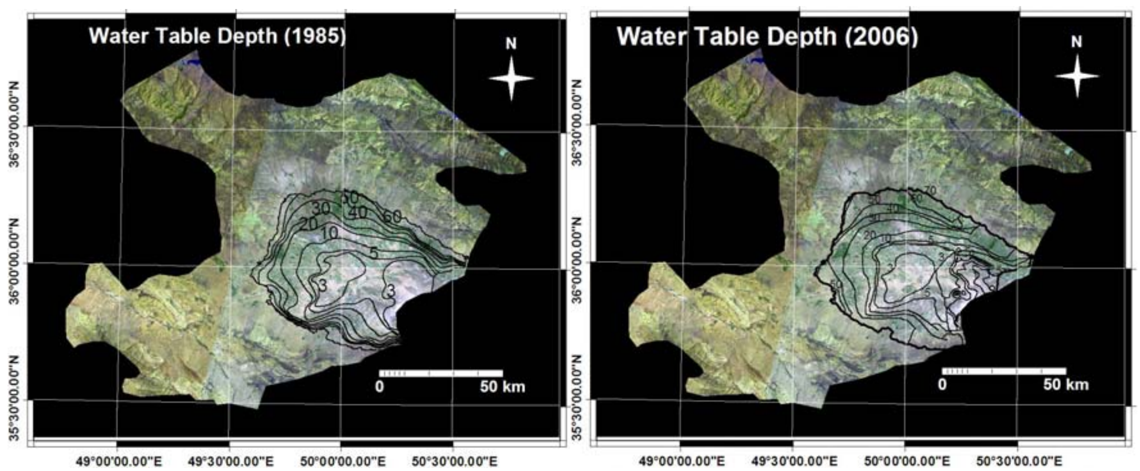

Figure 2. Minimum water table depth (m) for years 1985 (left) and 2006 (right).

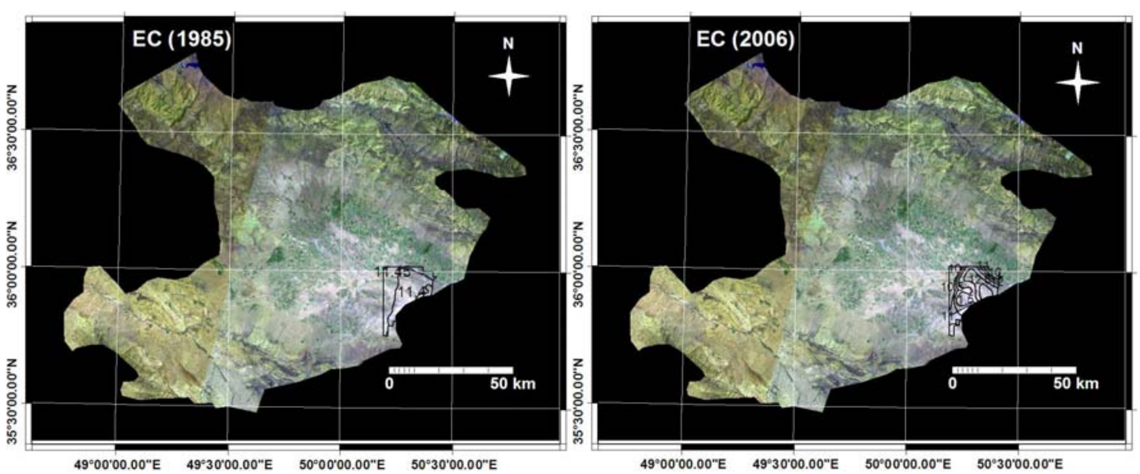

Figure 3. Maximum ECe (dS/m) for years 1985 (left) and 2006 (right).

METHODOLOGY To investigate change detection of soil salinity distribution in Qazvin Plain, two scenes of Landsat/TM and ETM+ images of July 7, 1999 and April 15, 2004 with path/row of 165-035 were used. Also, 136 samples of top soil (0-30 cm depth) were analyzed to determine electrical conductivity of soil extract (ECe) in 136 control points. ECe of top soil in control points which were distributed within a grid in salinized area were used to classify soil salinity in five salinity levels of Table 2. To find best combination of spectral bands of images, optimum index factor (OIF) method was used. Also some spectral bands were used to clarify soil salinity on the base of their correlation with ECe measurements. Regression model between ECe of soil samples in control points and selected spectral band was used to map soil salinity.

Table 2. Soil salinity levels.

Salinity Level	ECe (dSm^{-1})
Very Low Salinity	0-2
Low Salinity	2-4
Moderate Salinity	4-8
High Salinity	8-16
Very High Salinity	16<

RESULTS AND DISSCUSSION The optimum index factor (OIF) was applied to ETM+ bands covering salt-affected areas, and revealed that the best ETM+ three-band combination was 1–3–5 as Dwivedi and Rao (1992) suggested. But, band combinations 2–3–5 and 1–2–5 could serve as well because their OIF values were close to that of the first ranked (Table 3). Spectral bands of 5, 3 and 1 were used to develop regression models using ECe samples in control points. Several regression models were tested and the best model was a combination of exponential and logarithmic functions contrary to Abdinam (2004) and Taghizadeh Mehrjardi et al. (2008) suggestion. Table 4 shows the statistical indices to evaluate the selected function and Figure 4 shows the model. As shown in Figure 4, ECe increases as digital number of Channel 3 increases. Increase in digital number of Channel 3 means decrease in vegetation cover and indirectly it means decrease in quality of soil chemical status because of consecutive evaporation from waterlogged soil. The regression function was used to classify top soil salinity in Qazvin Plain (Figure 5) and was led to classify three classes of moderate to very high salinity. Figure 5 shows that soil salinity has been increased from 1999 to 2004. It may be because of drought occurring during this period of time. Area of each salinity class was extracted from histogram of two images to compare and detect top soil salinity change (Figure 6).

Table 3. OIF index highest ranking.

Rank	Band Composition	OIF
1	Ch1, Ch3, Ch5	67.29
2	Ch2, Ch3, Ch5	65.22
3	Ch1, Ch2, Ch5	65.13
4	Ch1, Ch3, Ch7	63.38
5	Ch1, Ch2, Ch7	61.46
6	Ch2, Ch3, Ch7	61.30

Table 4. Regression model and analysis of variance.

Regression Model					
Model Definition		Obs. No.	R^2 (%)	Durbin-Watson	
ECe = a+b*exp(CH3)+c*ln(Ch3)		136	55.67	1.7	
Variable	Value	Standard Error		t-ratio	Prob(t)
a	-9.40	2.20		-4.26	0.00004
b	7.17e-10	2.47e-10		2.90	0.00434
c	9.09	0.82		11.08	0.00000
Analysis of variance					
Source	DF	SS	MS	F-ratio	Prob(F)
Regression	2	683.91	341.95	83.52	0
Error	133	544.53	4.09		
Total	135	1228.44			

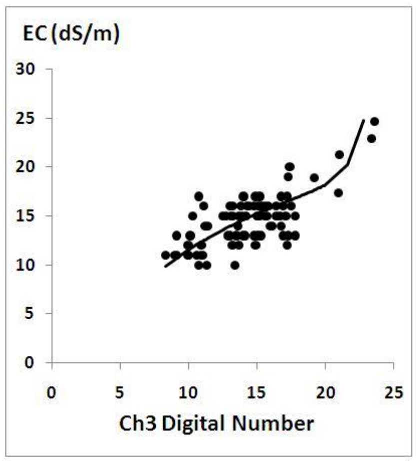

Figure 4. Regression model.

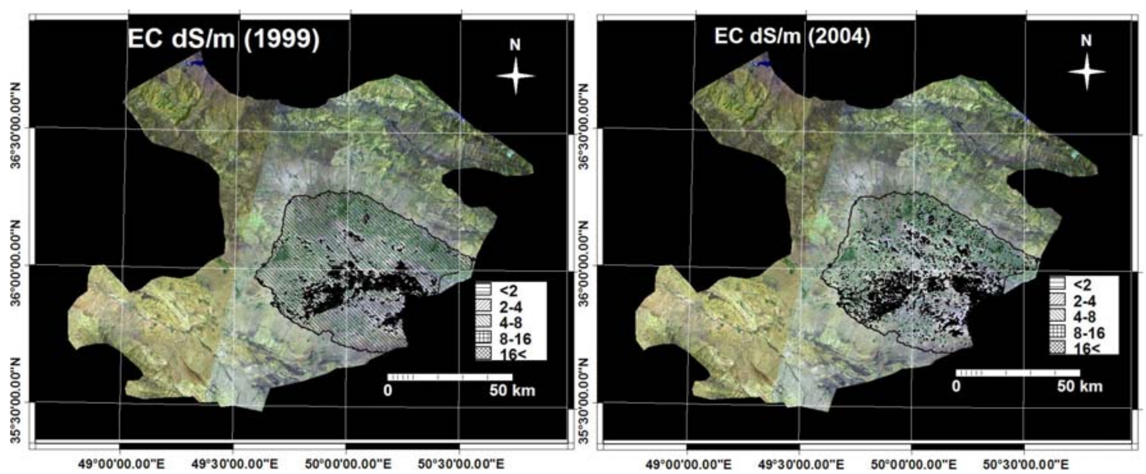

Figure 5. Soil salinity classification in Qazvin Plain for 1999 (left) and 2004 (right)

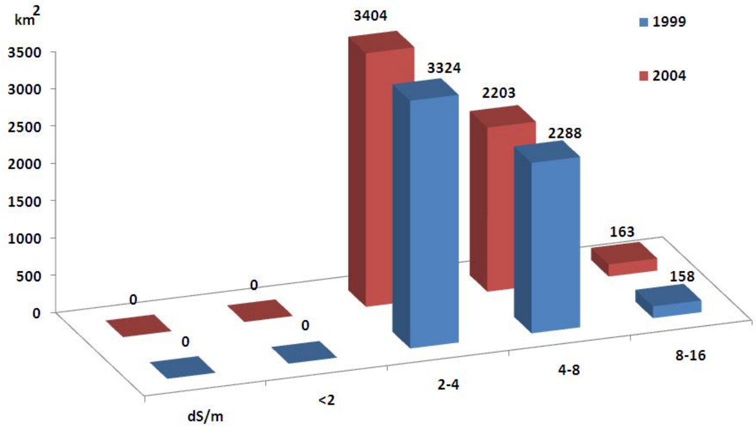

Figure 6. Change in salinity class areas in Qazvin Plain during 1999 to 2004.

Figure 6 shows that 59, 38.2 and 2.8 percent of Qazvin Plain area has had salinity from moderate to very high, respectively in 1999 and 57.7, 39.6 and 2.7 percent of area lays in moderate to very high salinity in 2004. Results show that areas of moderate salinity and very high salinity soils decrease 2.3 and 3 percent, respectively. Whereas, areas of high salinity soils increase 3.8 percent.

CONCLUSION To investigate soil salinity distribution in Qazvin Plain Landsat/TM and ETM+ images were used as well as soil extract analysis in 136 control points. OIF method showed that combination of bans 1, 3 and 5 was the best combination. Several regression models were tested and an exponential-logarithmic function of channel 3 digital number was found as the best model. The model was used to map soil salinity for two dates of 07/07/1999 and 15/04/2004. Comparison of results showed that for two years top soil salinity classes lays in moderate to very high salinity and shows a change of 2.3 and 3 percent decrease in area of moderate and very high salinity soils, respectively and 3.8 increase in high salinity soils area.

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