Quantifying of the spatial distribution of salt-affected land in Central and Southern Iraq

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The Iraq Salinity Project is an initiative of Government of Iraq, Ministries of Agriculture, Water Resources, Higher Education, Environment, and Science and Technology, and an international research team led by ICARDA – the International Center for Agricultural Research in the Dry Areas, in partnership with the University of Western Australia, the Commonwealth Scientific and Industrial Research organization (CSIRO) of Australia, the International Water Management Institute (IWMI), Sri Lanka, and the International Center for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates.

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This technical report series captures and documents the work in progress of the Iraq Salinity Project, in its seven research themes, working at the regional, farm and irrigation system scales. Technical reports feed into the *Iraq Salinity Assessment*, a synthesis and solutions to solving the problem: Situation Analysis (Report 1); Approaches and Solutions (Report 2) and Investment Options (Report 2).

Key words: southern Iraq, central Iraq, spatial distribution, remote sensing, irrigation, salinity mapping.

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Quantifying the spatial distribution of salt-affected land in the central and southern Iraq

1. Summary

Despite some difficulties experienced in executing parts of this research component, significant progress has been made and some inspiring results obtained, thanks to the full efforts of all team members.

To achieve the planned objectives there is still a way to go. It is too early to draw conclusions at this stage. Based on the team's achievements to date and what was understood in the previous phase, the tasks for next steps of this research are now clear.

Work and achievements to date

(1) Investigation of the vegetation condition and produced relevant maps via time-series remote sensing analysis. The trend of vegetation condition change and degraded areas in both pilot sites and the Mesopotamian Plain have been tracked and identified. However, whether the observed changes, or rather, degradations are related to salinization, climate change or irrational land management still remains to be investigated. With very limited field data, the team provisionally named the produced regional map as vegetation condition map, but for the sake of prudence, not a 'salinity map'.

(2) While interesting correlations were made between soil salinity and remote sensing indicators (as one of the targeted research outputs), the remote sensing salinity models still need more effort by the team, as well as additional field work and acquisition of relevant satellite images.

(3) To meet the requirements of points (1) and (2), the team will adjust its sampling scheme from random sampling to stratified sampling. Only in this way, will it be possible to move forward and achieve the models development and regional salinity mapping, and accomplish the successive tasks such multi-temporal salinity mapping as planned.

(4) For the analysis of the causes leading to salinization in Mesopotamia – and for more investigation to be done in other pilot sites, following the approach we have demonstrated in Musaib – a close interaction with other research components, such as B and especially G, is essential. Another focus should be on the impacts of climate change that might have already provoked influence on salinization in the region.

2. Introduction

Salinization is one of the most active land degradation phenomena in Mesopotamian in the central and southern Iraq. It is estimated that approximately 60% of the cultivated land has been seriously affected by salinity; and 20-30% has been abandoned (FAO, 2011); even in the non-abandoned agricultural land the yield has declined by 30-60% as a consequence of salinization. The mechanism behind is that the soluble salts concentrated in the topsoil and subsoil interfere with the growth of most crop plants as a result of increase in soil osmotic pressure. This unfavorable biophysical process leads to conversion of the most highly productive land into salinized land dominated by salt-tolerant natural plants such as *Tamarix*. In fact, salinity is not a new issue but has been a permanent problem since Babylonian Period (Schnepf 2004, FAO 2011), and provoking negative impacts on crop production. Thus food security meets a harsh challenge in Iraq. It is hence of prime importance to investigate the distribution and intensity of salinity in space and analyze the causes of salinization. Having so done, we will be able to provide relevant advices and suggestions for decision-makers or competent departments for their land management planning and practices, and to mitigate the severity of salinization and its impacts on crop production in the region.

In regard of the salinization phenomenon in Iraq, several authors have conducted studies or assessments, for example, Jacobsen and Adams (1958), Dieleman (1963), Al-Layla (1978), Al-Mahawili (1983) and Abood et al. (2011). These assessments allow us to have a general understanding on salinity in Iraq. International organizations such as FAO/UNSECO together with the Ministry of Agriculture (MoA) have carried out soil classification and produced soil map of Iraq in 1960 (Buringh 1960); FAO investigated salinity severity in Western Asia including Iraq in 1980 and 2008. However, the outdated old maps with low resolution (e.g., soil map dated 1960) cannot meet the requirement of land management and for salinity control. For this reason, the map updating with higher resolution, higher accuracy and reliability becomes essential for local governments.

It is hence the objectives of Component A to conduct a pertinent regional scale investigation on and mapping of the distribution of the salt-affected soils, and develop an operational and relevant multi-scale salinity assessment methodology for the central and southern Iraq. The study area and five pilot sites are shown in Figure 1.

3. Methodology

In general, salinity assessment and mapping are conducted either by field soil sampling and data interpolation, or by remote sensing in conjunction with the field investigation. In this research, we proposed an integrated multi-scale methodology involving both field sampling and investigation with remote sensing application. The latter is a very promising tool for large scale monitoring and assessment.

3.1 The state-of-the-art of salinity mapping by remote sensing

Since 1970s, a number of authors namely Hunt et al. (1972), Driessen and Schoorl (1973), Steven et al. (1992), Mougenot (1993), Rao et al.(1995), Metternicht (1998), Eghbalm et al. (1998), Metternicht and Zinck (2003), Shao et al. (2003), Farifteh et al. (2006), and so on have investigated soil surface features related to different types of salinity, and their spectral and radar signatures. These studies have laid a solid foundation for salinity assessment and mapping using remote sensing technology. However, the challenges are also evident:

- Salt concentrated in subsoil is not easy to be detected by optical remote sensing; even in the topsoil (surface), if the salt content is below 10–15%, it is difficult to be discriminated from other soil surface components (Mougenot et al. 1993); however, reflectance increases with the increase in quantity of salts at the terrain surface. Salt-affected soils show relatively higher spectral response in the visible and near-infrared regions of the spectrum than non-saline soils do, and strongly saline-sodic soils present higher spectral response than moderately saline sodic soils (Rao et al. 1995).

- Halide, borax and sulphate groups are not sensitive to spectral reflectance in different spectral region if they are not hydrated; nevertheless, increase in soil moisture and the presence of OH^- groups in the crystal lattice contribute to decrease in the reflectance in the middle- and near-infrared bands (Epema 1990, Mougenot et al. 1993).
- As well as soil moisture and the quantity and mineralogy of salts, halophyte vegetation and even salt-tolerant crops such as barley, cotton, and alfalfa can modify the overall spectral response pattern of salt-affected soils, especially in the green and red bands (Metternicht 1998, Rao et al. 1995).

In spite of these challenges, a number of successful applications have been reported and are summarized in the following paragraphs.

2.1.1 Optical (visible, infrared and thermal) remote sensing

A number of authors have applied optical remote sensing for salinity mapping, for example, (1) Brena *et al.* (1995) used multiple regression analysis of the electrical conductivity values and spectral observations to estimate the electrical conductivity for each pixel based on sampling sites in the field in Mexico and they generated a salinity image (or map) using the regression equation; (2) Zhang et al. (1997) revealed the high correlation between NDVI values and soil electrical conductivity, allowing to separate saline–alkaline soils from non-affected ones; (3) Golovina et al. (1992) found that the health status of cotton plants and cotton yield, which can be assessed by remote sensing, can be used as salinity indicators because of their strong correlation with electrical conductivity; (4) Steven et al. (1992) stated that near to middle infrared indices (Normalized difference for TM bands 4 and 5) are proper indicators for chlorosis in the stressed crops (due to salinization); (5) Dwivedi and Rao (1992), Eldeiry and Garcia (2010) have explored the best combination of Landsat TM bands for separation of the salt-affected soils from others; and Al-Khaier (2003) demonstrated that the combination of B4 (1.65μm) and B5 (2.16μm) of ASTER imagery, e.g. (B4-B5)/(B4+B5), is a suitable descriptor for overall salinity assessment in the bare agricultural soil/fallow (R^2 =0.86); (6) Garcia et al. (2000) developed salinity models related to blue and near infrared bands, NDVI and simple ratio indices; (7) Lobell et al. (2010) employed MODIS data to investigate its relation with salinity and found that the EVI (Enhanced Vegetation Index) developed by Huete et al. (1997) has better correlation with salinity than NDVI; (8) Furby et al. (2010) identified the change of saline land by incorporating Landsat TM images with DEM (Digital Elevation Model); and (9) Abdelfattah et al. (2009) used Landsat images to classify and identify different level of salinity and found high agreement with ground-measurement.

Furthermore, Metternicht and Zinck (1996, 2003), Goossens and Van Ranst (1998) noticed that incorporation of the TM thermal band 6 improves the separability of saline-alkaline soils from non-affected ones or from gypsiferous and coarse-textured desert soils. This incorporation substantially increased both the overall and the class accuracies. Igbal (2011) developed the Normalized Difference Salinity Index using the thermal and near infrared band of Landsat images for salinity mapping.

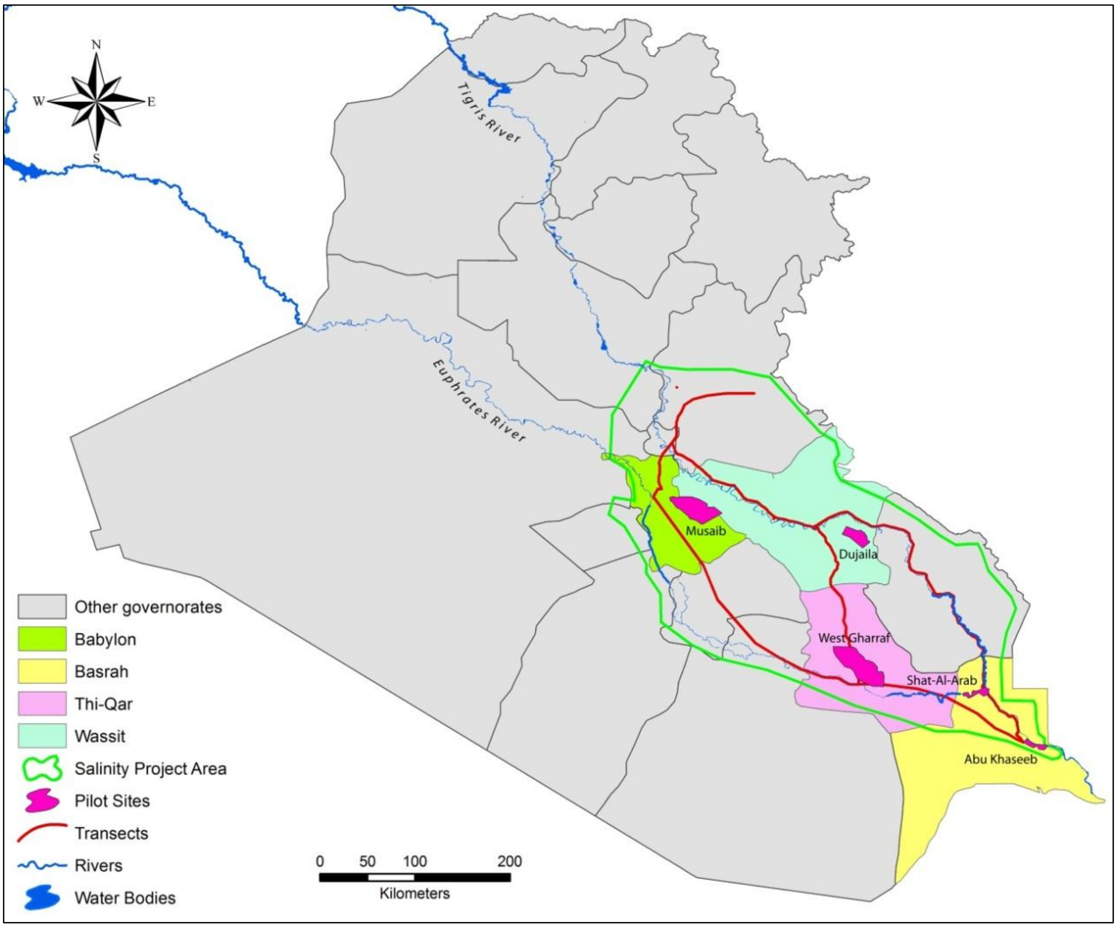


Figure 1: location of the study area and five pilot sites in Iraq

2.1.2 Radar remote sensing

Another interesting attempt is the application of radar data for salinity mapping. As Chaturvedi et al.(1983), Metternicht (1998), Singh et al. (1990), and Taylor et al.(1996) argued, the microwave C-, P- and especially L-bands are considered adequate for detecting salinity in different settings since the signal can penetrate through the surface and reach subsoil at a depth of > 2 m (depending on the soil characters and moisture). The independence from atmospheric conditions offers an advantage over the optical and infrared satellite-borne sensors. Because of the differential behavior of the real and imaginary parts of the dielectric constant, microwaves are efficient in detecting soil salinity. While the real part is independent of soil salinity and alkalinity, the imaginary part is highly sensitive to variations in soil electrical conductivity. This allows the separation of saline soils from others. Shao et al. (2003) also found that soil salinity has a significant contribution to the backscatter coefficient of RADARSAT SAR images and thus it is possible to use C-, especially L-bands for salinity assessment. However, as Mougenot et al. (1993) worried about, the disadvantage of radar application is that the characterization of saline soils using complex dielectric constants determined by radar backscattering inversion techniques requires some soil moisture data, as the measurements depend principally on dielectric constant and permittivity determined by moisture conditions, chemical and biological compositions. Overall, the microwave region, in particular, L-band, has low amounts of spectral confusion and the best separability between saline areas and non-affected ones.

Some authors (Chaturvedi et al. 1983, Singh and Srivastav 1990) have tried to use microwave brightness and thermal infrared temperature synergistically to detect salinity.

In summary, the different electromagnetic spectral regions have different sensitivity to the salinity–alkalinity classes and they are complementary to each other. Hence a relevant combination or merging of the visible, shortwave infrared, thermal infrared and microwave imagery may provide a good opportunity to increase the separability of salinized soils from others and the efficiency of salinity assessment by remote sensing.

3.2 Approaches and procedures adopted in this research

Based on the above review, we understand that although challenging, remote sensing is still the most promising tool for salinity detection, mapping and assessment. The following indicators and combinations were taken into consideration in our multi-scale (from pilot sites to region) and multi-temporal (from 1990 to 2012) study:

- Combination of various types of vegetation and non-vegetation indices;
- Tasseled Cap features (brightness, greenness and wetness) and Principal Components through spectral transformation;
- Thermal band;
- Radar backscatter coefficient; and
- DEM

The procedures are unfurled as follows:

(1) **Data documentation and digitization:** The existing salinity assessment data and maps for the pilot sites namely Musaib, Dujaila, Shat-Al-Arab, Abu Khaseeb and West Gharraf (see Figure 1 for location) were collected and digitized. Available historical soil samples were documented and initially analyzed.
DEM with resolution of 30 and 90 m and time-series meteorological data from 1980 to 2011 were obtained.

(2) **Field sampling and investigation:**
Musaib: 30 soil samples including 13 profiles and 15×3 = 45 EM38 readings;
Dujaila: 17 soil samples + 65 EM38 readings; and
West Garraf: 19×3 = 57 EM38 readings.

(3) **Satellite imagery acquisition:**
More than 190 Landsat TM and ETM + images from 1985 to 2012 were obtained for the research areas; and time-series MODIS data (MOD13Q1) from Jan 2000 to Dec 2011 were acquired.

(4) **Image preprocessing:** Landsat TM and ETM+ images were atmospherically corrected using FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) model.

(5) **Multispectral transformation:** For Musaib and Dujaila sites, a set of vegetation indices including NDVI, SAVI (Soil Adjusted Vegetation Index), SARVI (Soil Adjusted and Atmospherically Resistant Vegetation Index), EVI (Enhanced Vegetation Index), GDVI (Generalized Difference Vegetation Index), Tasseled Cap features (brightness, greenness and wetness), Principal Components (PC), and surface temperature (T) were converted from Landsat images for the period 1990-1994 and 2009-2012.

(6) **Multiyear annual maximum NDVI combinations:** To tackle such combinations is aimed to avoid the problems related to crop rotation and fallow state of cultivated land that often occur in single date image processing, and also to remove the SLC-Off (Scan-Line Corrector Off) problem of the recent Landsat ETM+ images. These combinations were produced for Landsat ETM+ and MODIS data (2000-2002, 2004-2007, and 2009-2011).

(7) **Coupling analysis for remote sensing development:** Field measurements (salinity and EM38) from pilot sites (Musaib, Dujaila and West Garraf) were linked to different types of vegetation indices, especially NDVI and non-vegetation indices by simple or multiple linear regression models, to ascertain the relationship between soil salinity and remote sensing responses, and further develop remote sensing salinity models.

(8) **Regional-level vegetation condition and salinity mapping**: Based on the multiyear maximum annual NDVI combinations of MODIS data, a classification technique was applied to stratify vegetation conditions (including both crops and natural vegetation) in terms of its vigor or greenness. A trend for each of such vegetation condition was tracked to understand the change during the observed period.

4. Results and discussions

Although available data is still limited, significant progress has been made and interesting results obtained by following the above procedures. The results are demonstrated in two levels: local and regional scales.

3.1 Local scale: Pilot sites

As the basis, local level or pilot scale study is the key to implement the proposed method and procedure to develop relevant remote sensing mapping approach and models, and eventually regional scale salinity mapping.

3.1.1 Salinity and vegetation condition maps

For facilitating the comparison, some historical salinity maps were also presented together our remote sensing processing results. The maps are illustrated in line with the pilot sites.

(1) Musaib: Figures 2-5 show the salinity maps and vegetation condition change trend.

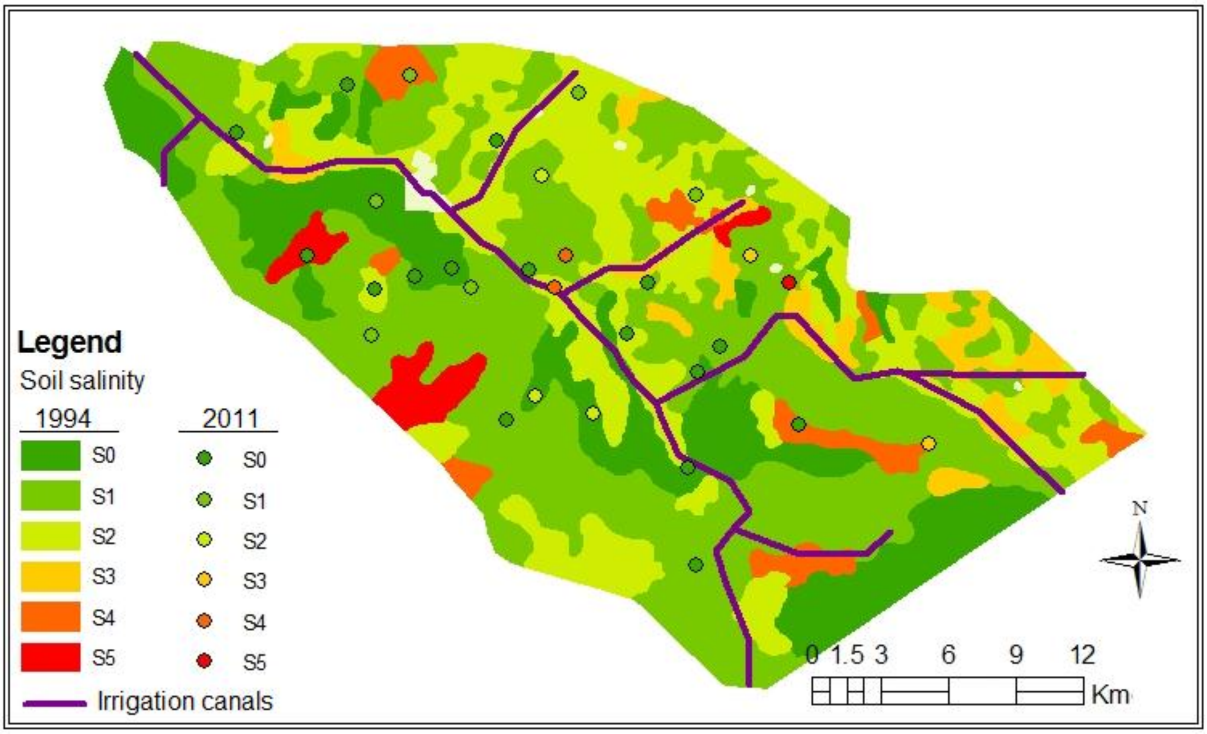


Figure 2: Soil salinity in 1994 (salinity map) compared with soil salinity in 2011 (recent field survey) in the Musaib pilot site.

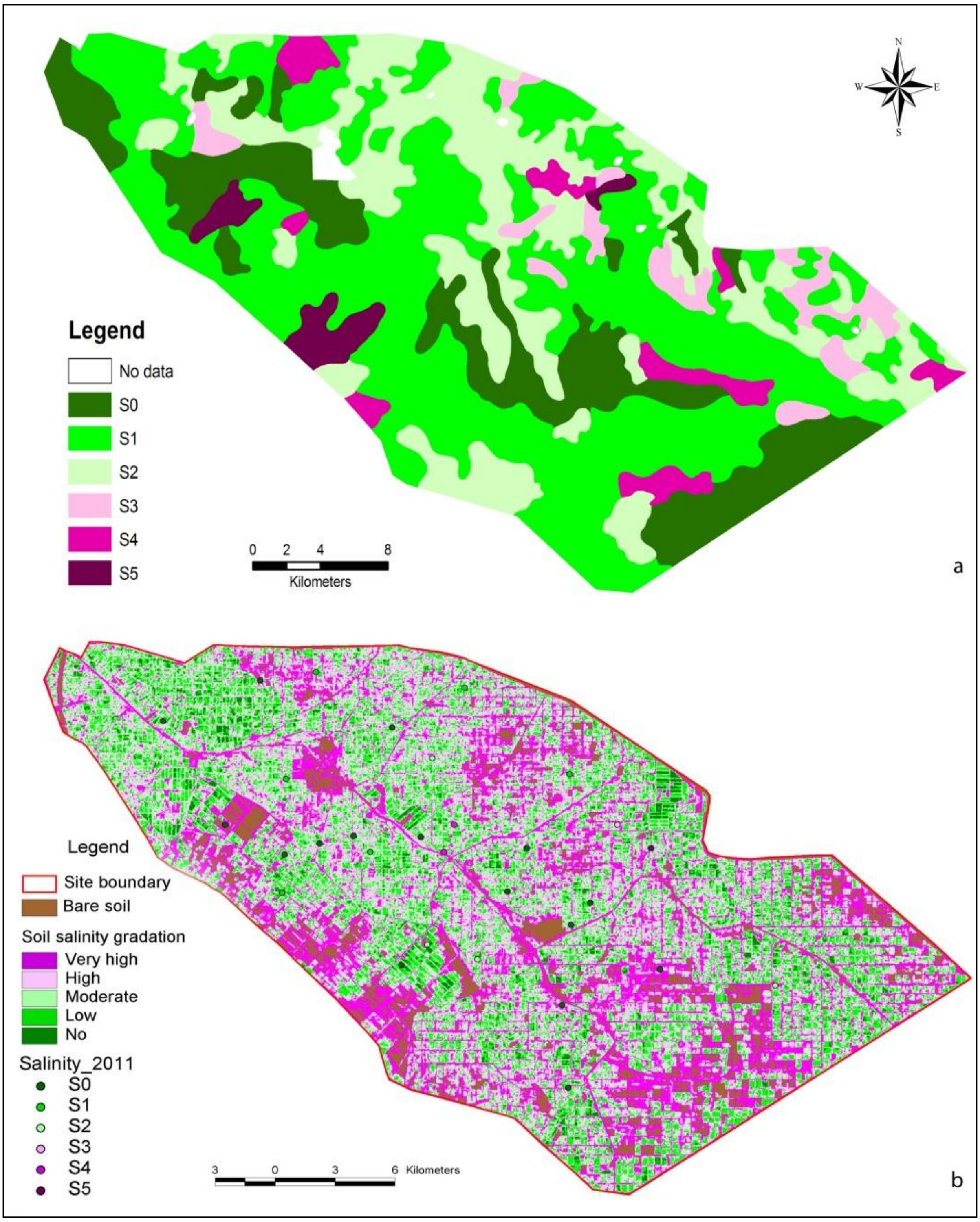


Figure 3: Salinity map of 1994 (a) and the draft salinity map of 2011 (b)

Note: (a) digitized historical salinity map and (b) produced using the multiyear annual maximum NDVI of Landsat ETM+ imagery 2009-2011

In Figures 2 and 3 (a, b), the difference between the two salinity maps is significant but is it is still too early to comment on this since the field work is not accomplished.

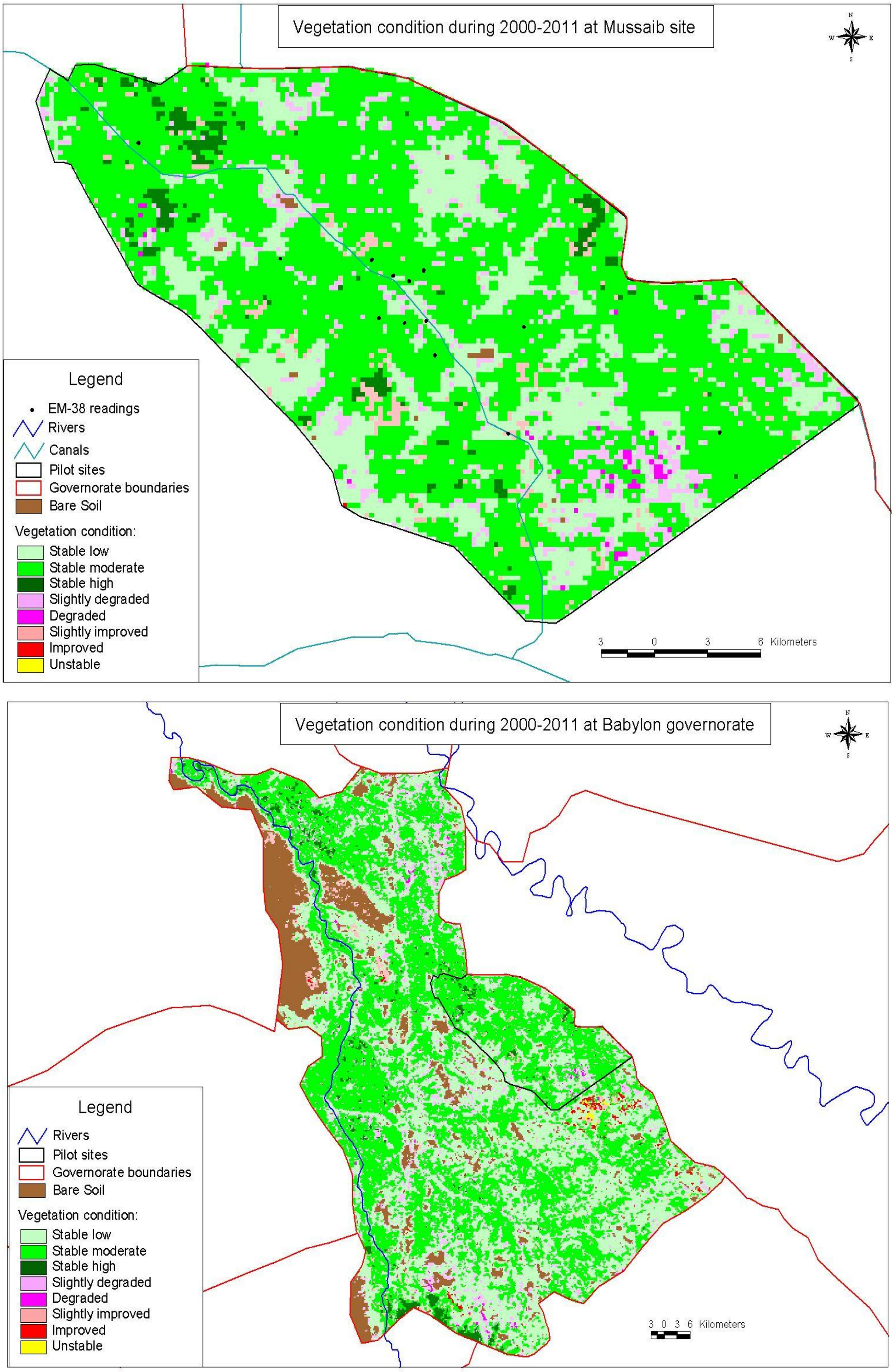
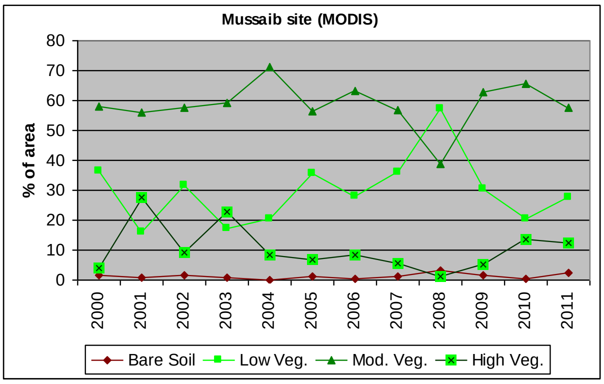


Figure 4: Vegetation condition in the Musaib site and the Governorate Babylon in the period 2000-2011 derived from MODIS data



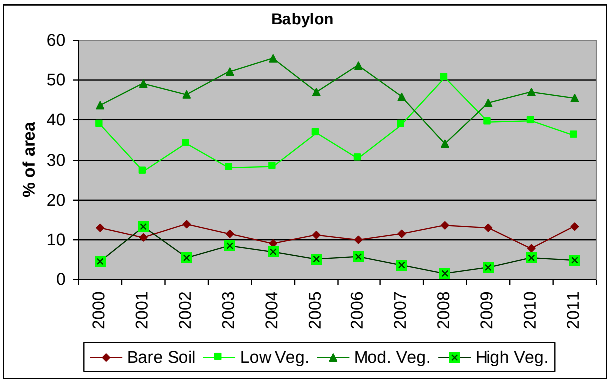


Figure 5: Vegetation condition trend at the Musaib site and Babylon

It is noted that in Figure 5 a clear change in low (rangeland) and moderate vegetation cover (rainfed cropland) not only in Musaib but also in the whole Babylon in 2008. Was it caused by rainfall variation or by change in land management? The question can be only answered by field investigation.

(2) Dujaila site: Figures 6-8.

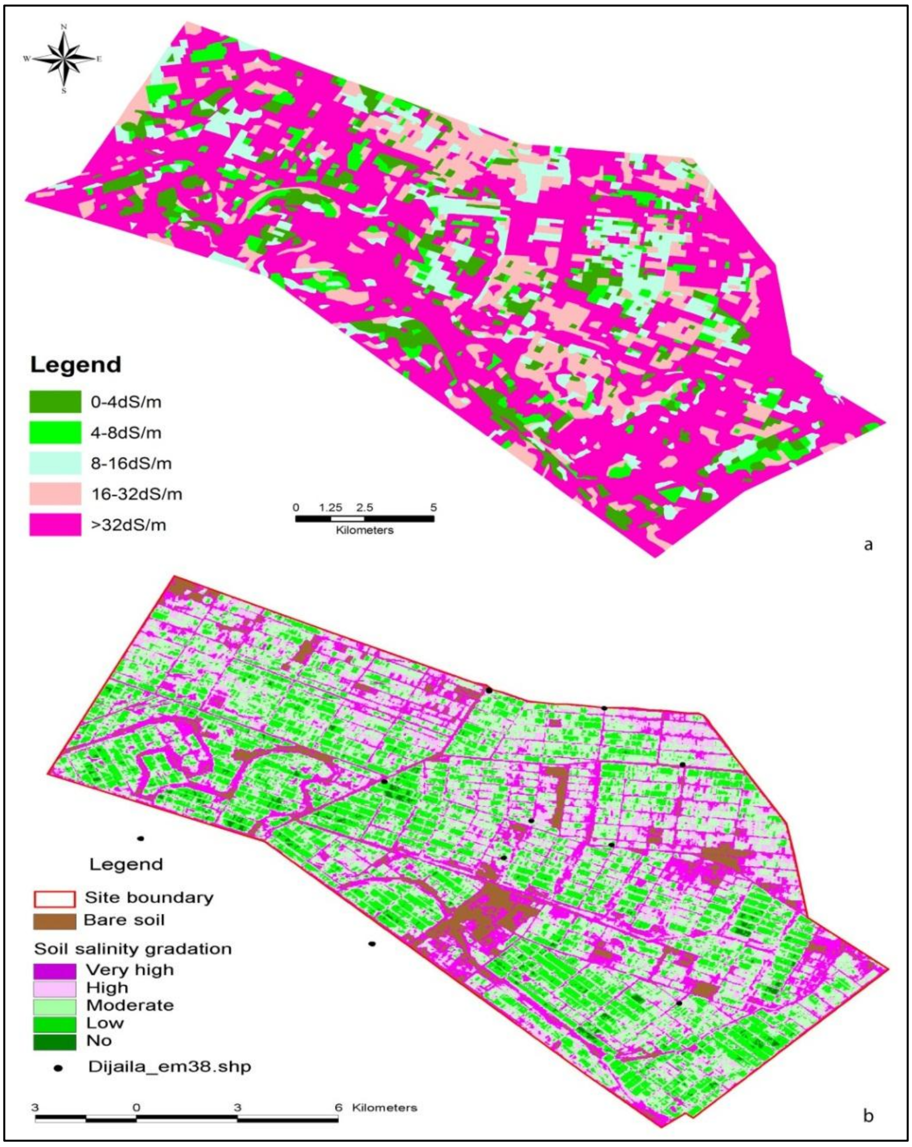


Figure 6: Digitized salinity map of 1958 (a) and our draft salinity map of 2011 (b)

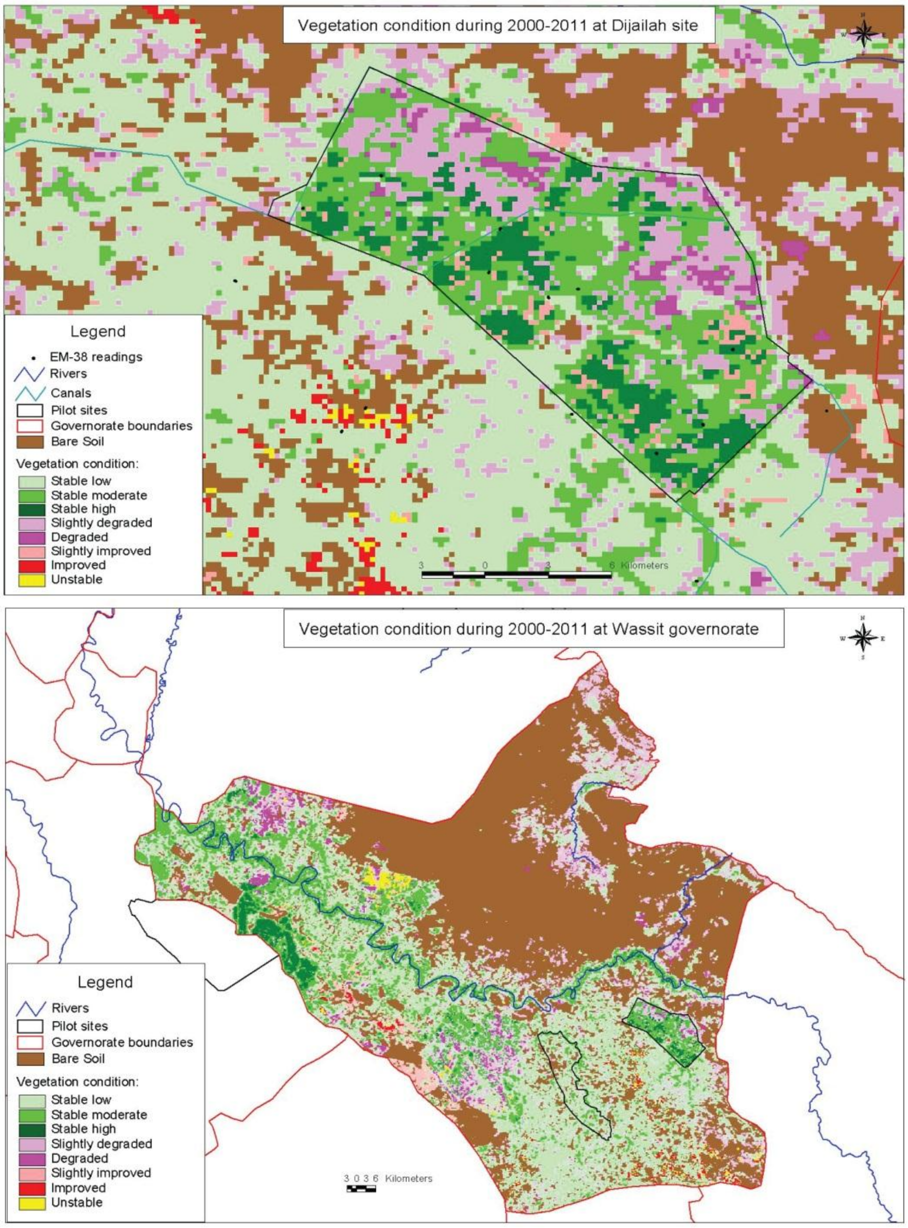


Figure 7: Vegetation condition in the Dujaila site in the period 2000-2011 produced from time-series MODIS data

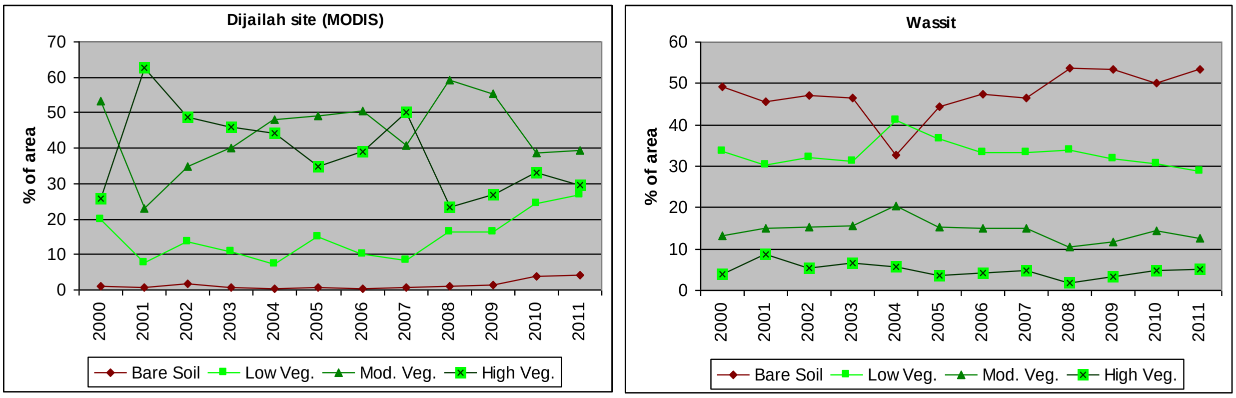


Figure 8: Vegetation condition dynamics in Dujaila and Wassit

Different from the Musaib site, high or dense vegetation cover (mainly irrigated cropland) interchanged dynamically with rainfed cropland (moderate vegetation). It's a result of water shortage or management change, or due to salinization?

(3) **West Garraf:** Figures 9-10

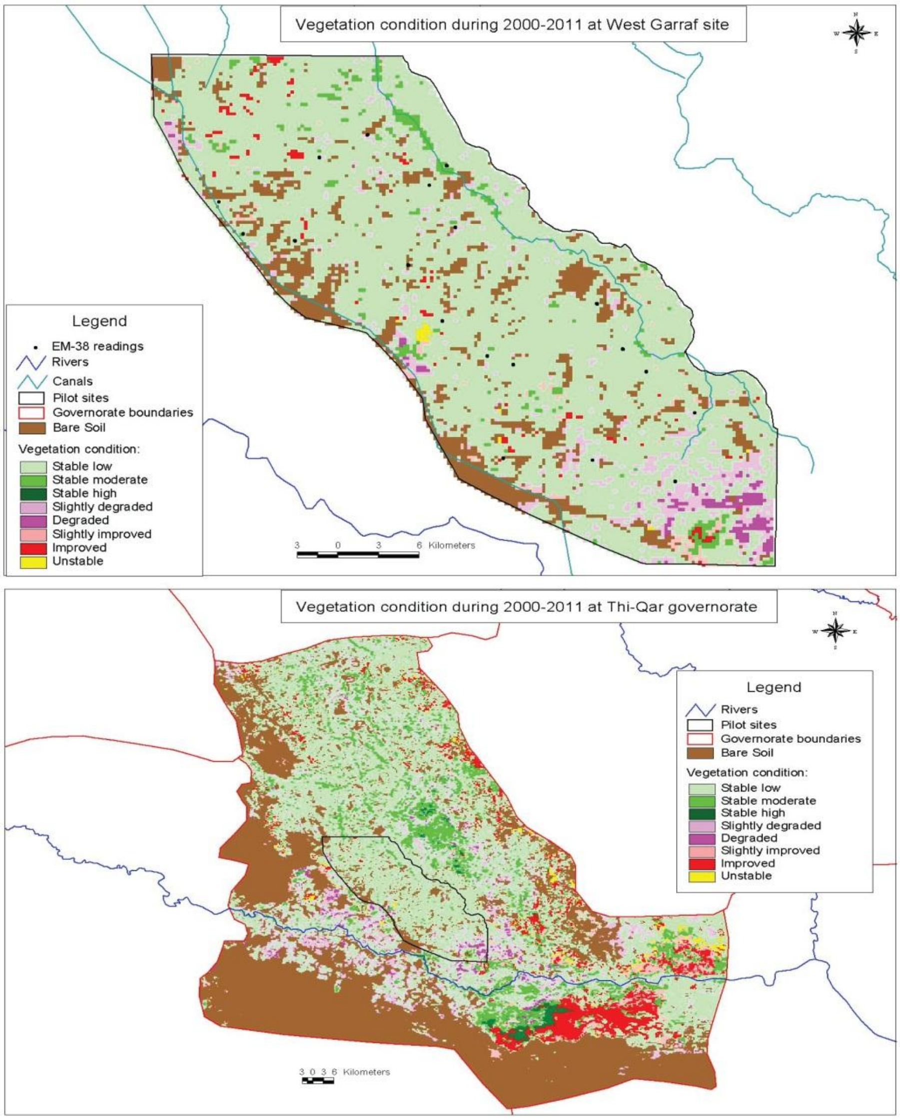


Figure 9: Vegetation condition maps of West Garraf in Thi-Qar

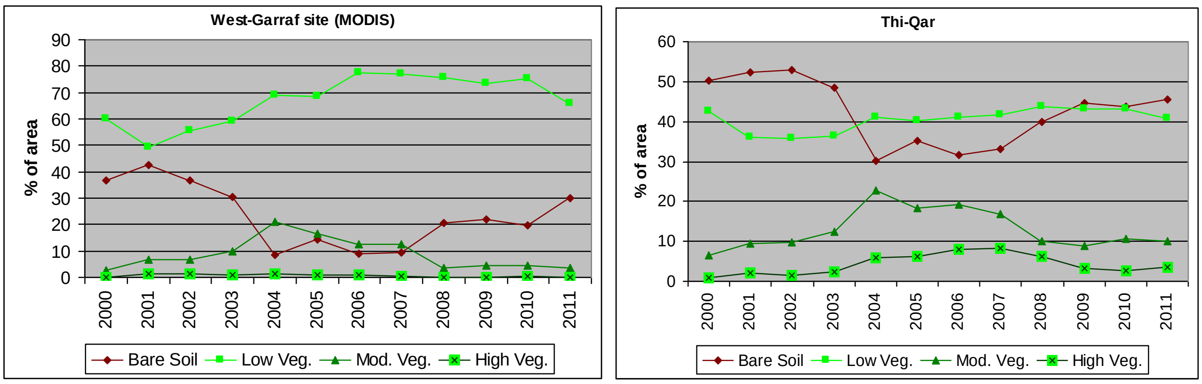


Figure 10: Change trend of the vegetation cover in West Garraf and its adjacent area

We can see easily that in the West Garraf site irrigated land has a very low percentage; the dominant land cover is rangeland (low vegetation cover) and bareland, interchanging with time. We checked their relationship with annual rainfall. But nothing interesting was found. There should be other factors (e.g.

inter-annual changes in cropping pattern, irrigation water availability, etc.) including salinity influenced on such vegetation dynamics and change between years.

(4) Shat-Al-Arab and Abu Khaseeb: Figures 11-12.

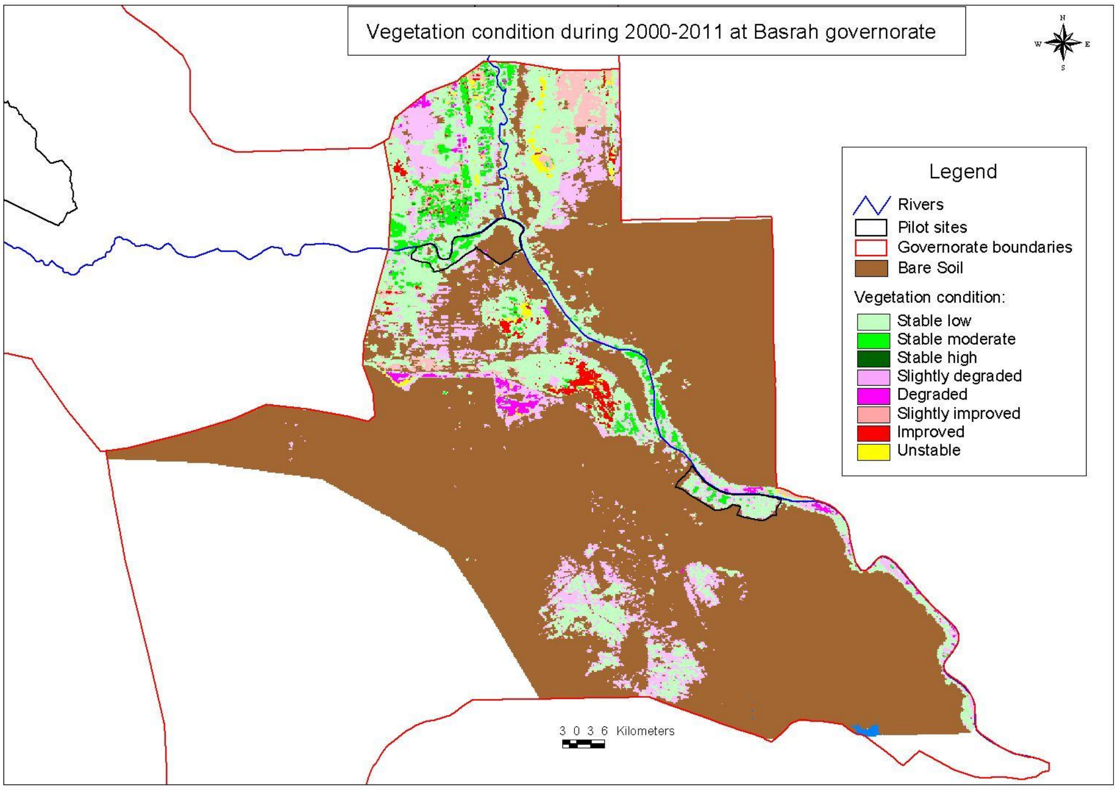


Figure 11: Vegetation condition map of Basrah (Shat-Al-Arab and Abu Ghaseeb)

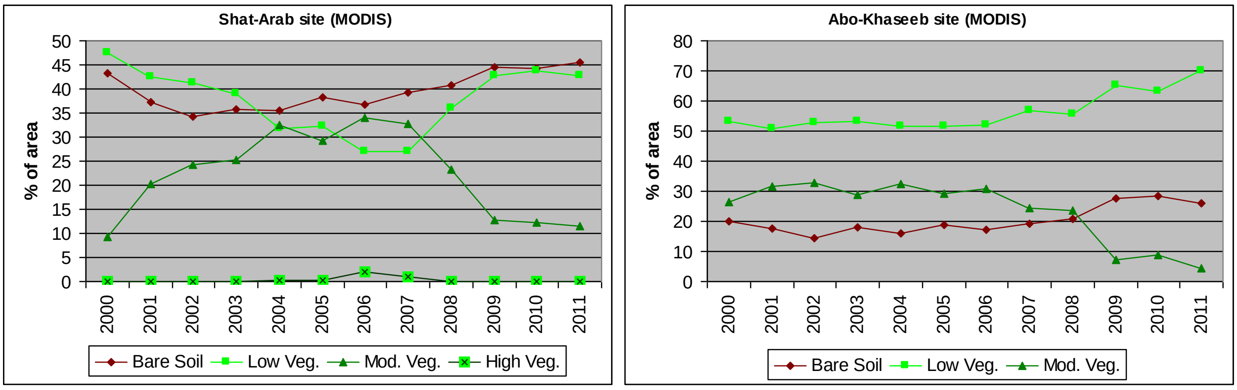


Figure 12: Dynamics of vegetation cover in Shat-Al-Arab and Abu Khaseeb

At the Shat-Al-Arab site, land cover is also very dynamic, especially the low vegetation and moderately vegetated areas. The reason for this change is not clear yet. Is it caused by salinity or rainfall variation, or land abandonment due to salinity?

From the above maps and figures, we obtained a general image about that land use/cover change is of strong variability in space. Different project sites or governorates have experienced different types of change trend. Whether such changes are associated with salinity or land management, we need more field investigation and data for further interpretation.

3.1.2 Models coupling remote sensing with salinity

For the Musaib site, while coupling the multiyear maximum vegetation /non-vegetation indices of 1990-1994 with the historical salinity data, we noted that the correlation is very low (R^2= 0.02-0.16). After checking the historical soil data (1993-1994), we got to know that there is a significant defect: they used one profile sample to represent all similar texture soil, which is not true in reality.

For the period 2010-2012, no strong correlation was found either between the measured EM38 (2012) and remote sensing indicators. Probably, the EM38 measurement was just made after rainfall or irrigation.

We had the same concern for the West Garraf site because the correlation is also very low.

The encouraging site is Dujaila. We found that EM38 measurements are highly correlated to various remote sensing indicators including vegetation indices and non-vegetation indices (e.g. temperature and infrared spectral index). The correlation coefficients are listed in Table 1. Among the vegetation indices, EM_V is best correlated to NDVI and GDVI (Generalized Difference Vegetation Index).

Table 1: Correlation coefficients between EM38 measurements and remote sensing indicators

	EM_V	EM_H	T	SAVI	GDVI	EVI	NDVI	NDII57
EM_V	1							
EM_H	0.980	1						
T	0.741	0.742	1					
SAVI	-0.773	-0.737	-0.776	1				
GDVI	-0.801	-0.767	-0.786	0.975	1			
EVI	-0.761	-0.726	-0.839	0.968	0.942	1		
NDVI	-0.802	-0.769	-0.834	0.983	0.988	0.976	1	
NDII57	-0.693	-0.672	-0.872	0.855	0.868	0.896	0.906	1

Note: EM_V and EM_H — Vertical and horizontal EM38 readings; T — at satellite brightness temperature, normally very close to the surface real temperature; SAVI — Soil Adjusted Vegetation Index (Huete 1988); GDVI — Generalized Difference Vegetation Index (Wu 2012); EVI — Enhanced Vegetation Index (Huete et al. 1997); NDVI — Normalized Difference Vegetation Index (Rouse et al. 1973); and NDII57 — Normalized Difference Infrared Index (Hardisky 1983) for TM bands 5 and 7.

3.2 Regional scale: Mesopotamia

Using the time-series MODIS data, we produced the regional vegetation condition map (Figure 13) with trend track shown in Figure 14.

It is seen in these two figures that the highly/densely vegetated area (mostly irrigated cropland) is stable; interchange occurs among the low vegetated area (mainly rangeland), moderately vegetated (largely rainfed) and bare land, in particular in 2004. The interesting thing is that the regional map (Figure 13) revealed the “slightly degraded” and “degraded” areas, to which we have to pay more attention in field investigation, to ascertain whether the degradation is a consequence of salinization or because of other factors. We should first of all calibrate the observed trend with climatic data, especially, rainfall data to avoid misleading while interpreting the remote sensing result.

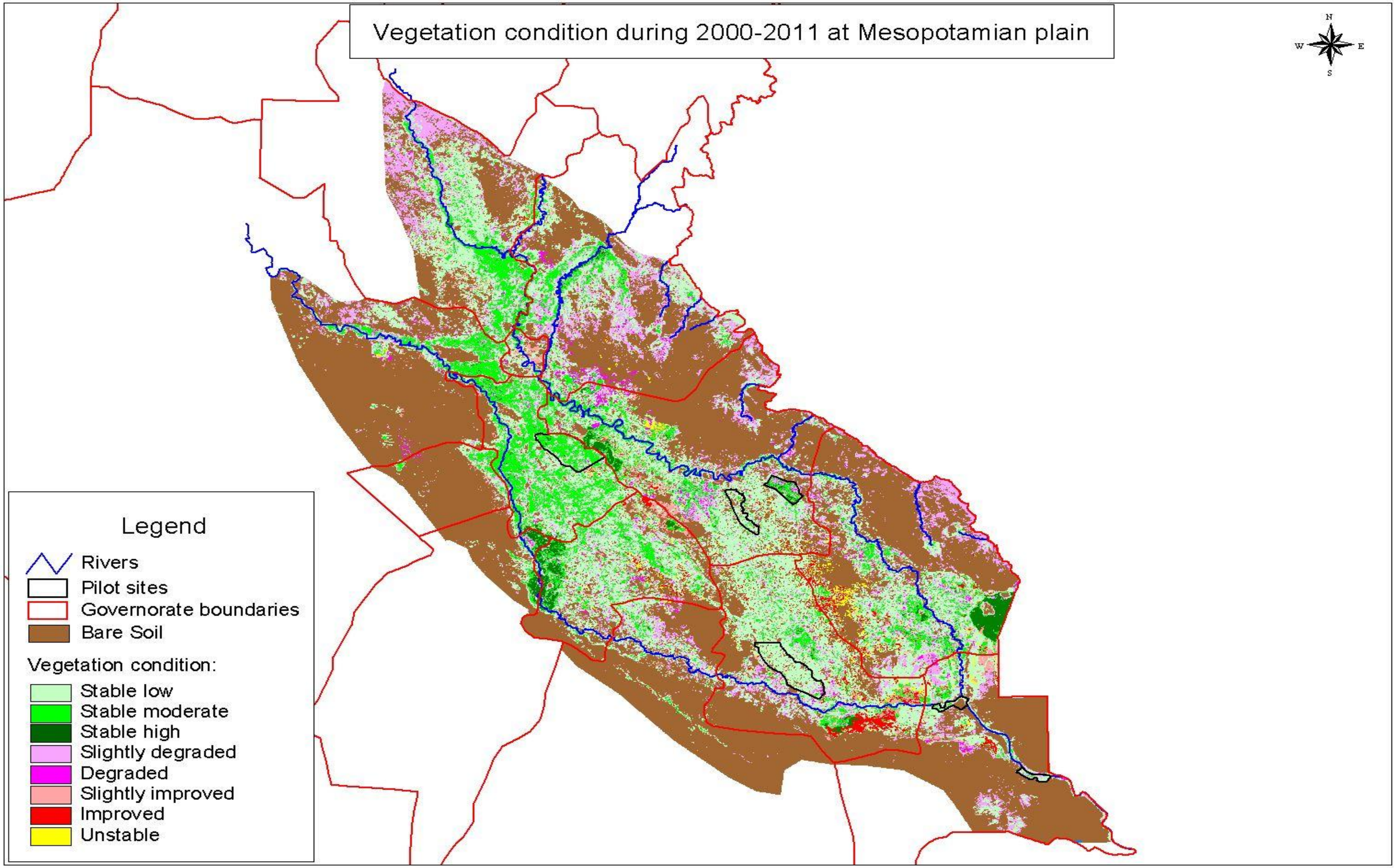


Figure 13: Vegetation conditions in the Mesopotamia Plain in the period 2000-2011 derived from MODIS data

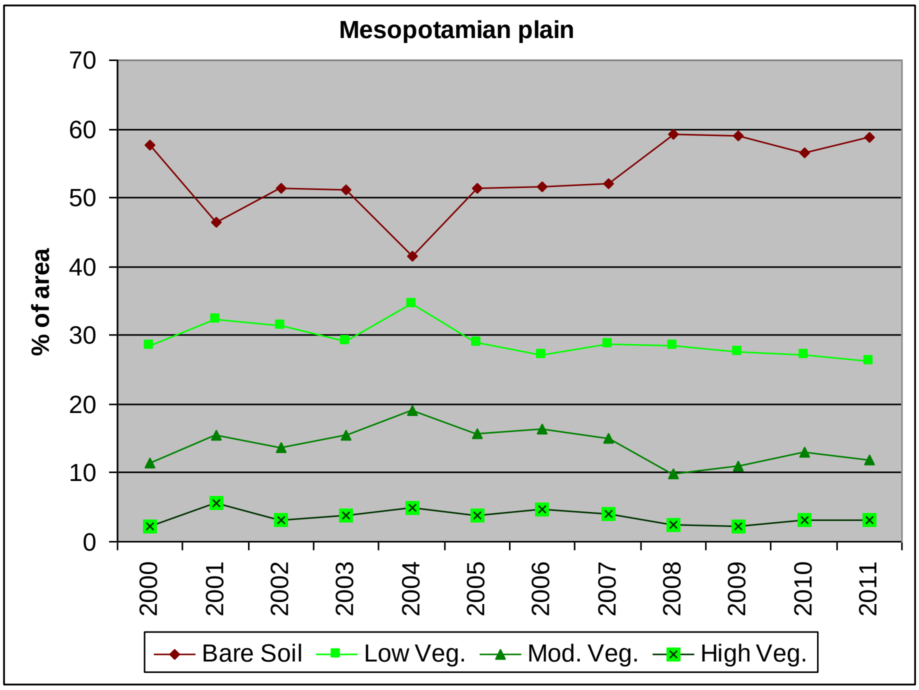


Figure 14: Vegetation condition trend in Mesopotamia in the past 11 years

3.3 Causes of salinization

3.3.1 Composition of salinity

Chemical analysis of the soil samples reveals that the salinity in Dujaila is mainly contributed by the association: Na-Ca-Mg-Cl (see Table 2). Different from the Dujaila site, it is K-Na-Ca-Mg-Cl combination in the Musaib site, where K plays an important role in salinity (Table 3).

3.3.2 Causes of salinization

3.3.2.1 Soil salinity in pilot sites:

Data for Musaib site were chosen for detailed analysis because of the availability of sufficient recent and historical information. The soil observations from different sources (sampled in 2011) were brought together in one shapefile, then overlaid with distribution of the irrigation channels, soil map and salinity map of 1994 (Figure 15). As a result of this analysis, the following relationships were investigated:

(i) Relationship between soil salinity at two different dates (1994 and 2011) with elevation of the field from sea level, depth of ground water, use of fertilizers, crop type, distance from irrigation channel and the soil type; and

(ii) Temporal changes in soil salinity between 1994 and 2011 and factors affecting these changes.

The results indicated some correlation between soil salinity and some biophysical factors that might explain some of the variability in the former (Table 4). There was a weak correlation between soil salinity at the two dates with elevation. This is mainly because the variation in elevation from sea level is very limited across the project site (with a minimum of 19 m and a maximum of 30m). Such small difference seems to be insufficient to create appreciable variations in soil salinity, although there was some correlation between elevation and the level of groundwater.

Table 2: Correlation coefficients of the chemical elements with salinity (EC) in Dujaila site (2011)

	DEPTH	EC	Na	K	Ca	Mg	Cl	SAR	SAND	CLAY
DEPTH	1									
EC	-0.369	1								
Na	-0.313	0.965	1							
K	0.061	0.155	0.133	1						
Ca	-0.578	0.784	0.696	0.166	1					
Mg	-0.413	0.705	0.651	-0.079	0.562	1				
Cl	-0.105	0.862	0.883	0.291	0.579	0.416	1			
SAR	0.169	0.518	0.671	0.058	0.233	0.087	0.652	1		
SAND	0.090	0.097	0.028	-0.219	0.022	0.017	0.174	-0.061	1	
CLAY	0.313	-0.170	-0.109	0.407	-0.182	-0.122	-0.106	0.110	-0.705	1

Table 3: Correlation coefficients among different soil properties in Musaib pilot site (2011)

	SAND	SILT	CLAY	LIME	O.M	pH	Ca	Mg	Na	K	HCO_3	Cl	SAR	GWL	EC
SAND	1														
SILT	-0.740	1													
CLAY	-0.229	-0.403	1												
LIME	0.126	-0.007	-0.225	1											
O.M	0.020	-0.461	0.729	-0.263	1										
pH	-0.015	-0.209	0.371	-0.452	0.493	1									
Ca	0.004	0.132	-0.258	0.331	-0.375	-0.612	1								
Mg	0.023	0.127	-0.267	0.291	-0.371	-0.584	0.988	1							
Na	-0.178	0.339	-0.294	0.413	-0.370	-0.828	0.667	0.648	1						
K	0.041	0.089	-0.259	0.350	-0.346	-0.697	0.964	0.946	0.764	1					
HCO_3	0.167	0.030	-0.038	-0.052	-0.027	0.028	-0.017	0.010	-0.024	-0.029	1				
Cl	-0.046	0.225	-0.321	0.312	-0.423	-0.733	0.943	0.942	0.839	0.953	0.011	1			
SAR	-0.236	0.315	-0.148	0.314	-0.137	-0.577	0.112	0.087	0.791	0.272	-0.034	0.361	1		
GWL	0.036	-0.332	0.414	-0.148	0.295	0.332	-0.307	-0.34	-0.392	-0.289	-0.138	-0.387	-0.250	1	
EC	-0.073	0.264	-0.329	0.359	-0.424	-0.792	0.893	0.887	0.913	0.929	0.022	0.986	0.499	-0.416	1

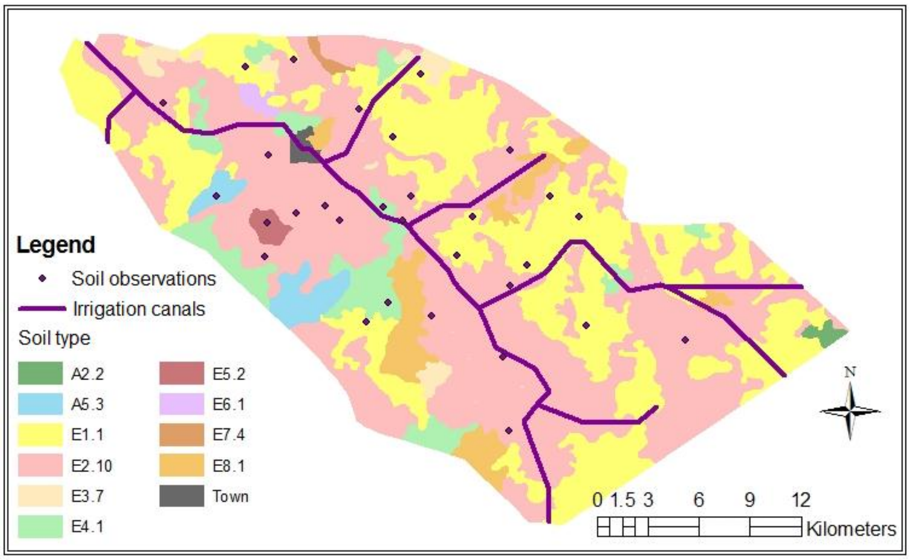


Figure 15: Recent soil observations with soil map and distribution of irrigation channels for Musaib pilot site.

Soil salinity of 1994 was not highly correlated with that of 2011, which indicates that change in soil salinity might have taken place during this period because this is a pilot site where efforts were directed to manage soil salinity through various management practices. However, detailed analysis of this change and the cause will be discussed separately.

Table 4: Correlation between soil salinity at two different dates and some biophysical factors

	Elevation	Salinity 2011	Ground water	Fertilizers	Crop	Distance to channel	Soil type	Salinity 1994
Elevation	1							
Salinity 2011	-0.10	1						
Ground water	0.18	-0.49	1					
Fertilizers	0.02	-0.34	0.30	1				
Crop	-0.09	-0.29	0.16	0.47	1			
Distance to channel	0.11	-0.15	-0.16	-0.10	0.07	1		
Soil type	0.07	-0.01	-0.02	0.01	0.06	-0.09	1	
Salinity 1994	0.07	-0.07	0.30	0.05	-0.20	0.18	-0.39	1

The soil salinity at the two dates indicated good correlation with the level of ground water. However, the correlation was higher between salinity of 2011 with groundwater level compared to the correlation between salinity of 1994 with groundwater level. It seems that the management practices applied during the period between 1994 and 2011 were also effective in causing some changes in the level of groundwater and consequently soil salinity. This is substantiated by the high correlation between groundwater level and some management practices such as the use of fertilizers, the crop type and the distance between the field and the irrigation channel. The effect of management practices such as the use of fertilizers and crop type on soil salinity is more obvious for the salinity of 2011 compared with that of 1994. On the contrary, the correlation between soil type and soil salinity in 1994 was much higher than the correlation between soil type and soil salinity in 2011 (-0.39 compared with -0.01). This is again indicating that the management practices were effective in causing some changes in soil salinity as reflected in 2011, while soil properties were more effective in causing soil salinity variation in 1994.

In summary, the current soil salinity at Musaib site correlate more with groundwater level and the related management practices (fertilizers and crop type) and less with soil type, while soil salinity back to 1994 correlated more with soil types. This indicates the influence of management practices on causing more variations in groundwater level and consequently soil salinity.

To better understand the changes in soil salinity and its causes, the salinity of the same site in 2011 was compared with same one in 1994 (see Figure 2 in the above section). The results implied that for most of the fields, soil salinity changed during this period. This was also indicated from the correlation analysis mentioned above. For sixteen fields, the soil salinity was less in 2011 compared with that in 1994, for nine fields, the soil salinity was higher in 2011 and for five fields there were no changes in soil salinity (Table 5).

Table 5: Changes in soil salinity between 1994 and 2011 for Musaib pilot site

Elevation	Ground Water	Fertilizer	Crop	Distance to channel	Soil type	Salinity 1994	Salinity 2011	Changes
29	200	yes	mixed	318	E2.7	S1	S0	high to low
29	115	yes	mixed	356	E4.2	S1	S0	high to low
23	130	yes	mixed	715	E1.8	S1	S0	high to low
27	160	yes	mixed	875	E1.2	S1	S0	high to low
23	110	yes	mixed	1034	E29.2	S1	S0	high to low
28	100	yes	mixed	3389	E1.8	S1	S0	high to low
24	125	yes	wheat	505	E29.6	S1	S0	high to low
19	117	yes	wheat	5603	E1.8	S1	S0	high to low
21	115	no	Fallow	952	E1.9	S2	S0	high to low
25	150	no	Fallow	1337	E2.8	S2	S1	high to low
26	110	yes	mixed	751	E11.3	S2	S1	high to low
27	120	yes	mixed	4804	E5.2	S2	S0	high to low
28	180	yes	Okra	516	E29.3	S2	S0	high to low
24	200	yes	mixed	3180	E11.5	S4	S0	high to low
29	110	yes	mixed	3816	E1.11	S4	S1	high to low
28	200	yes	mixed	3724	E5.5	S5	S0	high to low
26	100	yes	corn	3904	E4.1	S0	S1	low to high
25	90	no	Fallow	2291	E20.2	S0	S2	low to high
28	200	yes	mixed	1825	E29.6	S0	S1	low to high
22	150	yes	corn	2003	E1.8	S1	S2	low to high
20	85	yes	Fallow	1362	E20.3	S1	S4	low to high
28	50	no	Fallow	1422	E14.2	S1	S5	low to high
24	112	yes	mixed	2190	E14.2	S1	S3	low to high
26	115	yes	mixed	2275	E24.2	S1	S3	low to high
20	90	yes	Fallow	104	E2.8	S2	S4	low to high
22	105	yes	Corn	1726	E29.5	S0	S0	No change
25	200	yes	mixed	300	E29.7	S0	S0	No change
31	95	yes	mixed	3171	E24.4	S0	S0	No change
27	100	no	Fallow	6336	E29.2	S1	S1	No change
26	100	yes	mixed	1943	E29.6	S1	S1	No change

Generally, there is an unclear explanation of the changes in soil salinity between 1994 and 2011. This is mainly because the number of observations (30) is limited and doesn't allow for identifying clear pattern. However, there is a general trend of increase in soil salinity as the ground water is closer to the soil surface (shallow groundwater). This might be also associated with soil properties and management practices. There is also a general trend of salinity reduction as a result of using mixed cropping systems (rotation and intercropping) as compared with using single crop or fallow. The distance between the field and the irrigation channels has limited power in explaining changes in soil salinity. It seems that soil properties and management practices have more pronounced influence. Again, these interpretations are only preliminary and could be used as indicators. This points out the need for collecting more observations for other sites in the future to enable the evaluation of changes in soil salinity and possible approaches to control this problem. However, the preliminary results indicated that the approach followed could be useful to better understand extent and causes of soil salinity.

3.3.2.2 Salinization causes in Mesopotamia

The soils in Mesopotamia were called the "dark land" due to its high content of organic matter and very high productivity. But it's been subject to salinization since long time ago. From a regional view, salt-affected soils with an EC range from 5 to more than 300 dS/m and classified as "Saback" and "Shorah" according to their morphological, chemical and physical properties, is mainly distributed in the central and southern Iraq. The salinity level increases from the central to the southern part due mainly to the topographic effects and the elevation of sea-level. Based on our documentation, investigation and analysis, the causes of salinization in Mesopotamia can be summarized as follows:

(i) **Irrational management and practices:** Unsustainable irrigation method, e.g. the surface flooding irrigation without drainage system, has led to waterlogging and uprising of groundwater level and salt accumulation in topsoil after evaporation. This is supported by our analysis in pilot site Musaib.

(ii) **From groundwater:** Most of the groundwater table in the central and southern Iraq is very shallow with high salt content. In most areas the groundwater contains a mixture of salts. In the mixed solutions, the solubility and the salt concentration differ because the solubility of one salt depends on the presence or absence and concentration of others. The ratio of the various ions in groundwater is also influenced by crops and weeds which take specific ions. The influence of evaporation and transpiration is extremely important and both change with the seasons, the air humidity and the wind.

    The concentration of the salts in groundwater varies from 10,000 to 100,000 ppm. In many areas, it may be higher, up to 120,000 ppm. This depends on many factors mainly the drainage system and the rate of evapotranspiration of the groundwater.

(iii) **Salts from irrigation water:** The salt content of the irrigation water is different from one area to other within the Mesopotamian Plain. In general, the quality of irrigation water is not good, particularly in the southern parts of Iraq due to the water shortage from the two main rivers, Tigris and Euphrates.

(iv) **From the sea water:** In the southern parts of Iraq near Shat-Al-Arab, where soils consist of sea deposits or where they are regularly flooded by sea water, it is true.

(v) **Salts transported by the wind-blowing and rain:** The movement of eolian salts can become rather intensive in the some areas located near the western desert; and sometime rain-brought salt may be also locally important, e.g. in the Euphrates valley.

(vi) **Socio-economic situation of farmers**: Poor farmers have little capacity to invest for the maintenance of the irrigation and drainage systems. Without irrigation or bad irrigation, farmers may carelessly use the land or even abandon it due to the low productivity, leading to salinization; and also

(vii) Possibly due to **climate change:** In the context of climate change, Iraq has become one of the hardest-hit countries in the Middle East (UNDP 2010)[1]. In the past decades from 1970 to 2004, Iraq is one of the countries where annual mean temperature has increased by 1-2°C (IPCC, 2007). With the increase in temperature and frequent occurrence of droughts, and decrease in precipitation, salinization has become more intensive than ever due to strong evaporation and water shortage.

[1] http://www.uniraq.org/documents/UNEP-UNDP_Press_Release_Climate_Change_4_July_2010_eng.pdf

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