

Chapter 5

Assessing the Impact of Climate Change on Evapotranspiration and Soil Salinization

Mohammad Hassan Rahimian and Samaneh Poormohammadi

Abstract In this study a hypothesis was tested and evaluated: evapotranspiration of vegetation cover in dry saline waterlogged areas has a negative impact on salinization of soil resources due to pumping of saline underground water to the surface. For this purpose, reference, potential and actual evapotranspiration (ET) were simulated over the 2010–2039 time period via integration of Surface Energy Balance Algorithm for Land (SEBAL), MODIS remotely sensed satellite images and General Circulation Model (GCM)-derived data. Results of the study disproved the mentioned hypothesis; ET comparisons between green vegetated surfaces and bare abandoned lands represented the positive role of surface vegetation in alleviation of soil salinity in the studied conditions. This means that acceleration of the salinization rate is probable in a lack of vegetation cover condition, especially when the groundwater is saline-shallow.

Keywords Climate change · Evapotranspiration · SEBAL · HadCM3 · Salinization · Iran

Introduction

Iran, with about 25.5 Mha of slightly to moderately salt-affected soils and with 8.5 Mha of severe saline soils, is a country that is now faced with salinity problems in more than 20% of its area (Moameni et al. 1999). Due to different geologic,

M. H. Rahimian (✉) · S. Poormohammadi
RS & GIS Department, National Salinity Research Center (NSRC),
89195-315 Yazd, Iran
e-mail: mhrahimian@gmail.com; rahimian@insrc.org

climatic and hydrologic conditions in the country, different factors take part in soil salinization. These can be classified in two groups of natural and anthropogenic factors (Siadat et al. 1997). Environmental factors play the most important role on rate and spatial distribution of natural soil salinization. This type of salinization has affected the main portion of soil and water resources in the country and also agricultural yields, especially in arid, semi-arid and shallow saline groundwater environments. In such conditions, evapotranspiration (ET) is known as a main accelerative factor for salinization of soil resources.

This phenomenon (ET) is a combined process of transpiration from surfaces of plant leaves and evaporation from the soil in which the plants are growing. It counts the total volume of water lost through transpiration and evaporation processes and is expressed in cubic metres, or mm in a specified time period (Allen et al. 1998). Terminologically, three main types of ET can be defined: actual, potential and reference ET. Actual evapotranspiration (ET_a) is a process in which crop demand for water mainly controls, through crop leaves and stomata status, climatic conditions, environmental stresses, soil features and management practices. In contrast, potential ET (ET_p) is an indicator of crop-required water for healthy growth and productivity in non-stressed, disease-free and water-abundant conditions. Reference ET (ET_o) also demonstrates evaporative demands of the atmosphere and fully depends on climatic conditions. In fact, ET_o is known as a crop-independent term of ET. Among these different ET terminologies, ET_a seems to be paramount in illustration of wasted water through plant evapotranspiration, especially when the area is being under stress. It is also a good indicator for the illustration of CO_2 impact on stomatal conductance and photosynthesis and, therefore, crop productivity and water use efficiency (Le Houerou 1996). In areas with a shallow saline water table, actual ET, caused primarily by deep-rooted phreatophytes, is a significant factor for capillary rise and consequently salinity build-up hazard in the region. In contrast, when the soil is bare and also availability of water is limited to shallow groundwater, reference ET can demonstrate the power of ET for acceleration of capillary rise and movement of salts to the surface. Therefore, to investigate the effect of ET on salinization hazard in areas with a shallow saline water table, two conditions of bare soil and vegetated surfaces should be considered together with the help of ET_o and ET_a , respectively. Since ET is controlled by different climatic factors (e.g. temperature, sunshine, wind and humidity) it would be possible to simply monitor the impact of climate change on this phenomenon as well as the impact on soil salinization in areas with shallow saline groundwater.

At present, there are different approaches for determining actual ET. Examples of techniques used to estimate ET include water balance, lysimeters, micro-meteorological techniques such as Bowen Ratio and Eddy Covariance, and water table fluctuations (Scanlon et al. 2005). Information on ET in Iran is generally limited to meteorological station data used to estimate potential ET in different parts of the country. But none of these measurements provide estimates of actual ET. New procedures such as remotely sensed (RS) energy balance algorithms are other beneficial techniques for estimation of ET. The advantage of these

techniques is that they provide a good illustration of actual ET in the region both spatially and temporally (Allen et al. 2003). These techniques are now available in Iran in addition to the availability of high, moderate or low resolution satellite images (Poormohammadi et al. 2010).

In this study, Surface Energy Balance Algorithm for Land (SEBAL) was used to determine actual ET in the satellite overpass times. Since data derived from the General Circulation Model (GCM) is also available, a link between RS techniques and GCM data would help towards a proper assessment of climate change impacts on actual ET in future decades. The main objective of this study is to assess the impact of climate change on potential and actual evapotranspiration of bare lands and vegetated surfaces and, consequently, their impacts on changes of soil salinity status in Azadegan plain, west of Iran, a region with severe salinity and water-logging problems, which are the main hazards to its resources.

Materials and Methods

Study Area

The study area is Azadegan plain or Dasht-e-Azadegan (DA), one of the plains located in the lower part of the Karkheh river basin (KRB) in Khuzestan province, west of Iran. It lies between latitude 31°05' to 31°51' N and longitude 47°43' to 48°39' E (Fig. 1). The total area of DA is 334,000 ha, of which about 250,000 ha have been cultivated and used for agricultural purposes. Based on the statistics, the annual long-term precipitation in DA varies between 150 and 250 mm in different parts of the region. Meanwhile, annual evaporation is between 3,500 and 3,700 mm.

Methodology

Figure 2 shows the methodology used to estimate actual, potential and reference ET in the future period of time and, consequently, the impacts on soil salinization in two soil surface conditions of bare and green vegetated surfaces. As shown, in this study two main sources of data were used: historical and simulated data. Historical data includes T_{\min} , T_{\max} , sunshine, humidity and wind speed of the Bostan meteorological station from 1960 to 1989. In addition, a time series of satellite images was acquired and used as historical RS data. GCM data includes monthly data of the HadCM3 model for the projected period of 2010–2039 that resulted from GCM-runs for the Third Assessment Report (TAR) based on the IPCC¹-SRES scenario of A2 and B2, respectively. HadCM3 is a well-known GCM

¹ Intergovernmental Panel on Climate Change.

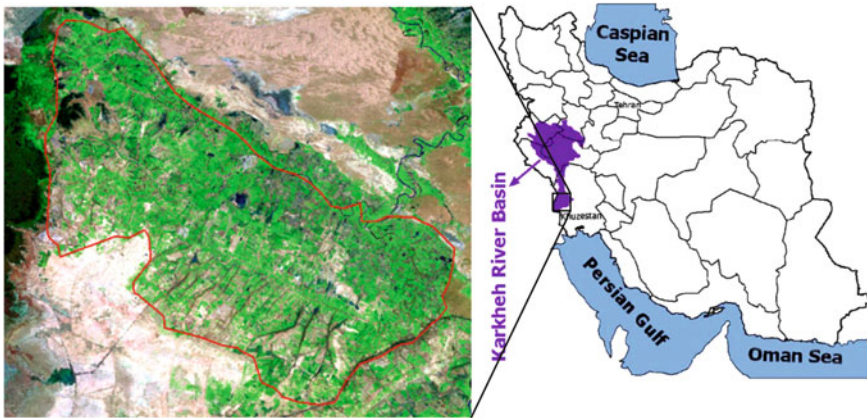


Fig. 1 Satellite image of Azadegan plain in the Karkheh river basin, Iran, and its geographical setting on the country map

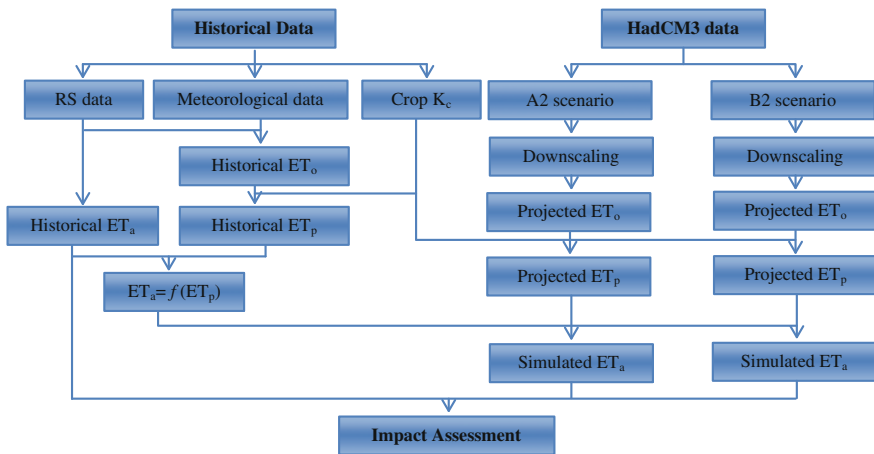


Fig. 2 Flow chart of the methodology used for impact assessment of climate change on evapotranspiration and soil salinization in Azadegan plain, west of Iran

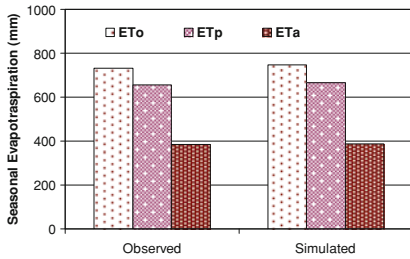
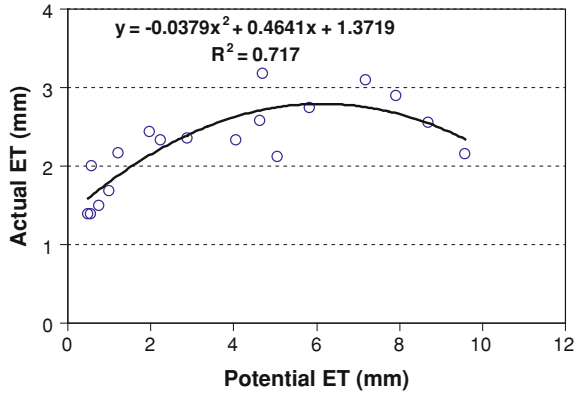
model that is used worldwide (Bates et al. 2008). Key assumptions in A2 scenario are a very heterogeneous world, strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development. B2 emission scenario represents a heterogeneous world with less rapid and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions (IPCC 2010). In fact A2 and B2 are the most frequently used emission scenarios in the world.

To determine actual ET, a time series of remotely sensed images and also ancillary climatic data was prepared. RS data included 18 cloud-free images that were acquired from the Terra (MODIS) satellite during the wheat cropping season. Surface Energy Balance Algorithm for Land (SEBAL) was used to determine ET_a . This algorithm is a relatively new procedure for estimating actual ET at different scales, e.g. farm, catchments and basin levels, and is now used widely around the world and also in Iran for computing crop water requirements under standard and non-standard conditions. Generally, SEBAL uses digital images acquired by satellites that record thermal infrared radiation in addition to visible and near-infrared radiation and computes ET on a pixel-by-pixel basis for the instantaneous time of the satellite overpass. This algorithm predicts ET from the residual amount of energy in the form of latent heat flux (LE) and is equal to $R_n - G - H$, of which R_n is above-ground surface net radiation, H is sensible heat flux and G is the ground heat flux. Details about the SEBAL procedure and steps for running the algorithm are presented in Bastiaanssen et al. (1998a, b), Tasumi et al. (2000). In addition, reference ET was calculated through the Hargreaves–Samani procedure (Alizadeh 2004). Thereafter, potential ET of winter wheat, as dominant vegetation cover, was calculated by considering its coefficient (K_c), which was varied during the growth season (0.3–1.15). Afterwards, relationships between ET_p and ET_a were investigated to develop the best-fit model for determining actual ET via potential ET. This model was then used to project actual wheat ET in the future period of time. For this reason, General Circulation Model (GCM)-derived data was linked to the Hargreaves equation, first to project reference and potential ET and then to insert into the developed model for simulation of actual wheat ET over the next three decades. This procedure was accomplished for the 2010–2039 projection period using HadCM3-A2 and HadCM3-B2 data, respectively. Since HadCM3 data was available in a low spatial resolution of $2.5^\circ \times 3.75^\circ$ (latitude by longitude), a stochastic approach was used for downscaling HadCM3 data (both A2 and B2) in the projected period of 2010–2039 (Massah Bavani 2006).

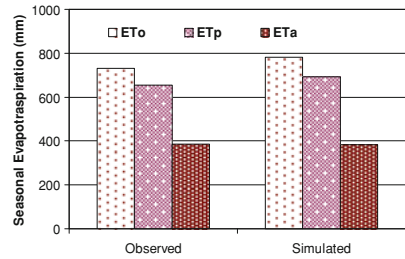
Results and Discussion

Figure 3 shows the best-fit quadratic model between historical data of ET_a versus ET_p . As was mentioned before, potential ET has been estimated through the Hargreaves equation by considering the winter wheat coefficient (K_c). Fair correlations could be found in the model ($R^2 = 0.72$). This model was then employed to simulate wheat actual ET during the 2010–2039 time period. As shown in the Figure, for ET_p of less than 6 mm/day, a higher value for ET_a would result in higher ET_p s through this model. After this point, the ET_a values would have a descending trend. It is noticeable that ET_p of more than 6 mm/day explains the shifting climate to some drier conditions, lack of water for evapotranspiration and consequently decrease of ET_a , as shown in the model outputs. Therefore, it is anticipated that the lower ET_a would be projected in

Fig. 3 Best-fit quadratic model for simulation of actual ET using potential ET in Azadegan plain, west of Iran



A2



B2

Fig. 4 Observed and simulated seasonal evapotranspiration (ET_o, ET_p, ET_a) for 2010–2039 using different scenario data (A2 and B2)

the future compared with the historical period of time, when the climate shifts to higher ET_p values.

Figure 4 shows averages of observed and simulated reference ET (ET_o), potential ET (ET_p) and actual ET (ET_a) in historical and projected periods of time, based on A2 and B2 scenario data, respectively. As was mentioned before, ET_a terminologically belongs to green vegetated surfaces and reflects the crop response to water availability, while ET_o illustrates the evaporative demands of the atmosphere and depends fully on climatic conditions of the region. ET_o can therefore represent the evaporation rate in bare soil and consequently explains the movement of salts to the surface.

As shown in this figure, both simulated ET_o and ET_p tend to higher values compared with observed values. In contrast, differences between observed and simulated values of ET_a for 2010–2039 seem to be negligible, both for A2 and B2 scenarios. This means that evaporative demand of the atmosphere would increase in the upcoming three decades, but green vegetated surfaces would prevent the wasting of water to the atmosphere. On the other hand, salinity of soil in vegetated surfaces tends to be constant, but salinity build-up hazard is expected for bare

surfaces. In fact, the role of vegetation cover seems to be significant in preventing the salinization hazard in the upcoming three decades in the region under investigation.

Conclusion

Key deterministic factors in salinization of soil resources in the studied condition included climate, vegetation cover, salt stores, and geological and topographical features of the region. In addition, the roles of these factors in contributing to salinization were interrelated. Among these factors, fluctuations of climate and surface vegetation cover were found more probable as results of climate and land use changes, respectively. Among these, the role of vegetative surface seems to be paramount in alleviating salinity in a long-term period and in a global changing climate. This means that acceleration of the salinization rate is probable in a lack of vegetation cover condition. In this way, tactics and strategies to mitigate climate change impacts via a proper land use and sustainable environment programme must be implemented and supported by decision-makers and social, political and other related sectors.

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