Concomitant Flow and Space Variations of Evapotranspiration due to Changes in LUCC under Seawater Intrusion in a Coastal Region

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Abstract

This paper provides a coherent pattern identification analysis of coastal land use and land cover (LULC) under the impact of seawater intrusion. This study analysis applied the 4-, 3-, and 2-band false color composite Landsat satellite data to characterize the LULC in the study area. The evapotranspiration (ET) and heat fluxes were estimated by using the SEBAL model with two-time phase thermal infrared band images and regional surface parameters. Our findings are as follows: 1) Due to its distance from the sea, the vegetation index gradually increases as the level of land use gradually increased. 2) The different influences of seawater intrusion in the study area resulted in significantly different influences of land surface parameters (LST, G_n, MSAVI, and Uindex) on ET. There are a variety of types of relational patterns between parameters (LST, G_n, MSAVI and Uindex) and ET (positive, negative, and no relationship). 3) Seawater intrusion significantly affected the spatial pattern of LUCC, which evidently affected the spatial distribution of ET. The spatial distribution pattern and change characteristics of ET were formed by double driving forces of seawater intrusion and LUCC under the background effects of regional climate.

Keywords: Evapotranspiration, Land use and land cover, Remote sensing, Seawater intrusion.

1. Introduction

The coastal zones consistently experience the strongest sea-land interactions which make sustainable land use management not only challenging, but at times, nearly intangible. As economic development has rapidly accelerated over the last few decades, many environmental problems, such as over-exploitation of land resources, seawater intrusion, overdraft of groundwater, coastal urban sprawl, and increased aquacultural or maricultural activities etc., have come to be recognized as driving forces behind changes in land use and land cover (LULC) patterns. The relationship between water flux and land use/cover changes (LUCC) needs to be further characterized in response to water sustainability impacts (Guan et al., 2001; Allen et al., 2005a, 2005b; Billi and Caparrini, 2006).

Estimating LUCC effects on the ET distribution with the use of remote sensing has become a focal point in the realm of land use dynamics (Baron et al., 1998; Tracy, 2004; Liu et al., 2005; Billi and Caparrini, 2006; Quan et al., 2006). Therefore, by incorporating remote sensing technologies, this paper aims to provide a coherent analysis of pattern changes in LULC in relation to ET variations under the impact of seawater intrusion. We attempt here to analyze the spatial patterns of land cover change and its effects on ET under the influence of seawater intrusion. Moreover, the goal of this study is to provide scientific

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support and a decision-making basis for regional land use planning, beach land resource development, and eco-environmental protection of coastal wetlands.

2. Methodology

2.1 The Study Area

The study area, which consists of varying geologic intensities of sea-land interactions, is located at Laizhou Bay in Shandong Province, China (see Figure 1) within the latitude of 36° 48' 43" ~37° 32' 49" and longitude 118° 37' 37" ~ 119° 44' 31". It measures approximately 97 km from east to west and 79 km from north to south. The total study area is 486,245 hectares. Land elevation drops mildly from 30 m to 2 m above sea level, and the length of the meandering coastal line within the study area is about 400 km. This active floodplain was formed by the release of sediment laden water from the neighboring river channel through regional morphological and sedimentary dynamics. Shouguang City, the Hangting area of Weifang City, and most of Changyi City are situated along this coastal line. The sediment distribution in the alluvial plain ranges from fine sand (close to the low water line) to the typical mud which is carried by flood currents. The climate system located close to the open ocean is a moist, warm, and temperate continental monsoon (Cao, 2002).

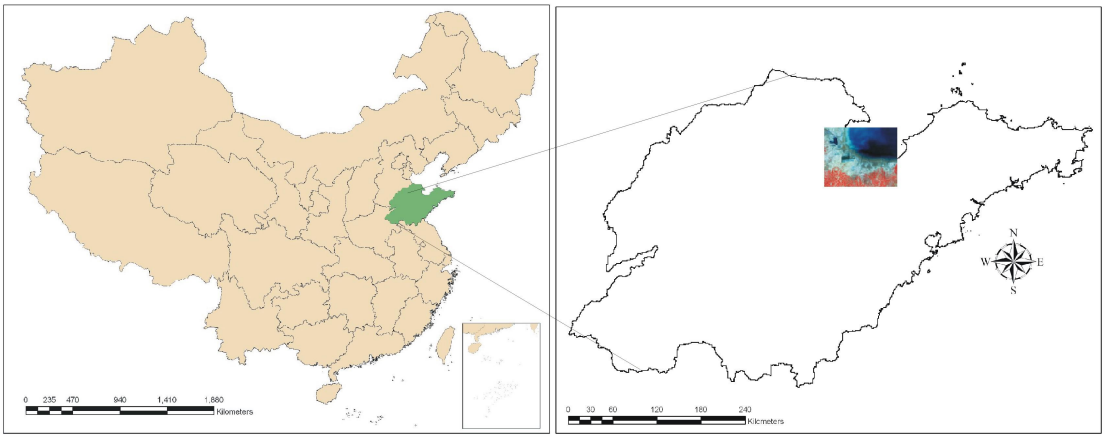
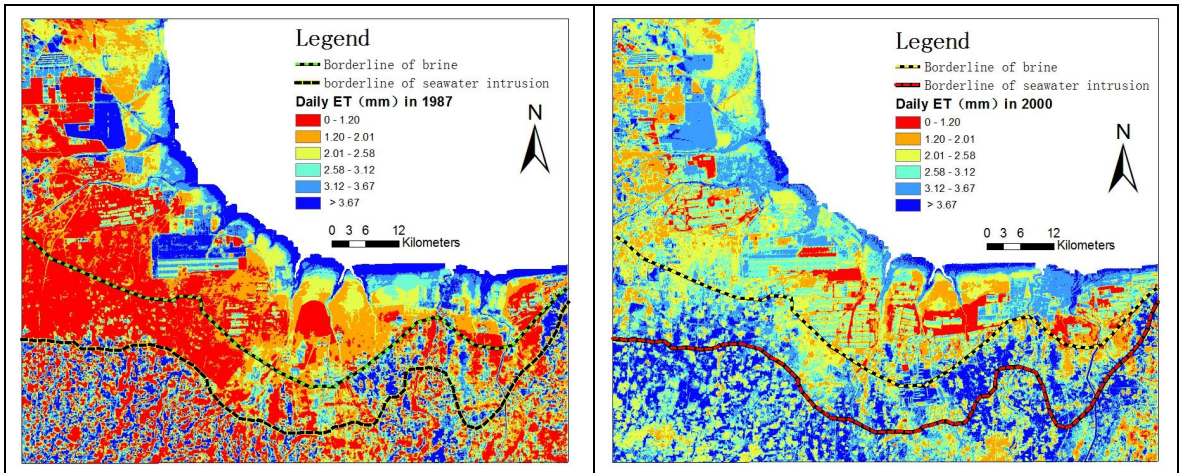


Figure 1. The location of the study area in Shandong Province, China



(a) ET in 1987 (b) ET in 2000

Figure 2. The distribution maps of ET in 1987 and 2000

2.2 Retrieval of the ET with Sebal model

With the use of LANDSAT satellite images, the heat fluxes and ET were estimated with the SEBAL model and were calculated with the Arc/Info 9.0 Macro Language (AML) and Compaq Visual FORTRAN 6.5 mixed-language programming (Bastiaanssen et al., 1998a, 1998b,2000; Gao et al., 2010) (Figure2). Our SEBAL-based computer package can be operated in a Microsoft Windows system using the ESRI GRID module as the major data format.

3. Results and Discussion

3.1 The Spatial Pattern Analysis of Essential Geophysical Parameters (MSAVI, LST Uindex, and G_n)

Over the past two decades, seawater intrusion has become a serious environmental management issue. Over the past ten years, field sampling campaigns have helped to clearly define the boundaries, such as the borderlines of the brine on the south coast of Laizhou Bay (Zhang and Wang, 2007), and also of the seawater intrusion in 2000 (Zhang and Peng, 1998) in the saline water, transition, and freshwater regions (Cao, 2002; Wang et al., 2002). Figure 3(a) and 3(b) show that the areas north of the brine borderline are in the saline water region. The remaining areas are largely comprised of fish ponds and saline-alkali land. The area south of the borderline of seawater intrusion is the freshwater region, which mostly consists of constructed land and farmland. The transition region between the borderlines of the brine and the seawater intrusion mainly consists of farmland, saline-alkali land, and sporadic rural residential areas.

The major characteristics of LUCC in the subregions are summarized as follows: 1) The saline water region accounted for 50.62% of the total area (481,928 hectares), and the changes which occurred in this region comprise as much as 79.23% of the total change area (134,940 hectares). Whereas the decrease also includes beach land, saline-alkali land, and grassland, the increase includes salt land, shrimp ponds, other constructed land, and farmland. 2) The transition region accounted for 21.19% of the total area; however, within the same time period, the changes in the transition region accounted for only 17.65% of the total change area in which the decrease of saline-alkali land and the increase of farmland and rural residential areas occurred. 3) The freshwater region accounted for 28.19% of the total area. The change in this region is much smaller, accounting for 3.12% of the total change area in which the decrease of farmland and the increase of rural residential areas and cities occurred.

Table 1: The essential geophysical parameters of different regions in 1987 and 2000

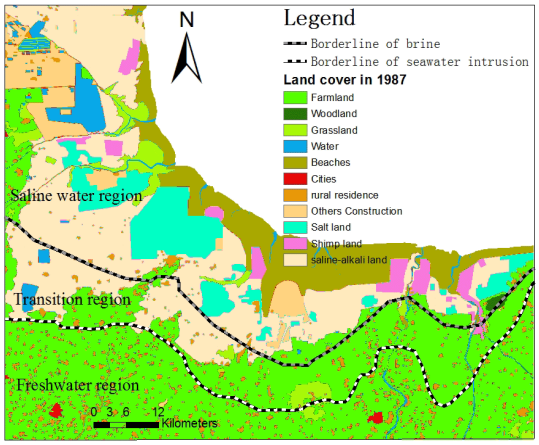
Regions	Saline water region	Transition region	Freshwater region	Study area
Area (%)	50.62	21.19	28.19	100
ET 1987 (mm)	2.03	1.45	2.15	1.95
ET 2000 (mm)	2.48	2.89	3.02	2.72
LST 1987 (^{o}C)	30.00	32.82	29.44	30.38
LST 2000 (^{o}C)	29.18	29.05	27.76	28.75
G_n 1987 (W/m^2)	17.71	15.11	15.12	16.42
G_n 2000 (W/m^2)	18.14	14.92	14.66	16.47
MSAVI 1987	0.05	0.14	0.23	0.12
MSAVI 2000	0.04	0.20	0.24	0.13
Uindex 1987	173.48	235.47	307.49	225.31
Uindex 2000	201.70	281.26	309.85	248.67

3.2 The ET Change Analysis in Different Regions between 1987 and 2000

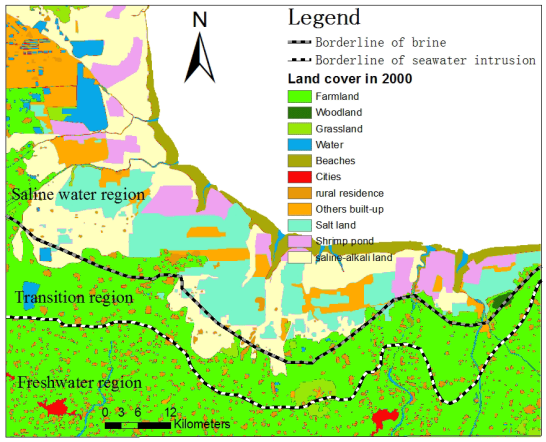
Figure 2 and table 1 display the spatial change in daily ET between 1987 and 2000. The annual average daily ET in the saline water region was 2.07 mm/day in 1987 and 2.53 mm/day in 2000, resulting in an increase of 0.45 mm. In the transition region, the annual average daily ET was 1.49 mm/day in 1987 and 2.94 mm/day in 2000, resulting in an increase of annual average daily ET of 1.45 mm. In the freshwater

region, the annual average daily ET was 2.19 mm/day in 1987 and 3.06 mm/day in 2000, resulting in an increase of annual average daily ET of 0.87 mm.

A comparison of the ET patterns associated with LUCC under the impact of seawater intrusion, as evidenced in Figure 2, shows that 14.45% of the entire study area experienced a decrease of ET in the 13 year time span between 1987 and 2000. This decrease occurred primarily in the saline water region. Alternatively, 56.32% of the entire study area exhibits an increase of ET which mainly occurred within the transition and freshwater regions. The unchanged areas of ET only account for 29.3% of the entire study area. As of 2000, the annual average daily ET increased by 0.45 mm/day in the saline water region, 1.45 mm/day in the transition region, and 0.87 mm/day in the freshwater region.



(a) Land use and land cover in 1987



(b) Land use and land cover in 2000

Figure 3. The LUCC of the study area

The ET variations resulting from the changes in land use over several decades are literally correlated with seawater intrusion on one hand, and economic development on the other. As shown in Figures 2, 3, this observation is evidenced by the gradient of LULC from the shoreline to the inland region, across the saline water region, the transition region, and on to the freshwater region. In the saline water region, affected by the seawater instruction, saline-alkali land evolves into salt land, beach land, and shrimp ponds with a low degree of land use. In the transition region, saline-alkali land, farmland, and rural residential units lead to a higher degree of land use. The highest degree of land use driven by the forces of economic development appear in the freshwater region with an initial change from saline-alkali land into farmland, subsequent changes into constructed land, rural residential units, and eventually evolving into big cities. The research findings clearly indicate that seawater intrusion has significantly and directly impacted LULC, and that alternatively, there has been an indirect impact on ET due to the varying levels of surface heat flux from 1987 and 2000.

4. Conclusions

After intense examination of the synergistic potential in the use of multi-source and multi-sensor data, this study applied the 4-, 3-, 2-band false color composite Landsat satellite data to characterize the LULC in the study area. With the aid of remote sensing images collected on May 7, 1987 (Landsat TM) and May 2, 2000 (Landsat ETM+), LULC was extracted based on computer-aided manual interpretation. The corresponding ET and heat fluxes were estimated by using SEBAL with two time phase thermal infrared band images and regional surface parameters. This enabled us to eventually link seawater intrusion to LUCC and ET variations over time.

The different levels of seawater intrusion in the three typical regions have varying effects of land surface parameters (LST, G_n, MSAVI, and Uindex) on ET. The relational patterns between these parameters and

ET are significantly different under the effects of seawater intrusion and LUCC. The research findings from a comparison of the ET patterns associated with the land surface parameters are summarized here.

The dominant land cover of the study areas consists of farmlands, saline-alkali lands, and built-up lands. The unused land cover types of saline-alkali and beach land cover large areas. The vegetation index has gradually become greater while the degree of land use has gradually intensified under the influence of seawater intrusion as the distance from the ocean increases.

The research findings clearly indicate that seawater intrusion has significant and direct impacts on LULC, and yet it indirectly impacts ET due to the varying levels of surface heat flux between 1987 and 2000.

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