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ORIGINAL ARTICLE

Ecological monitoring of wetlands in semi-arid region of Konya closed Basin, Turkey

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Abstract Wetland ecosystems are of global significance having productive, regulatory and informative function. These wetlands are crucial for the long-term protection of water sources, as well as the survival of its unique biodiversity. Most of the wetlands of Turkey are now facing serious threat from the anthropogenic sources and now near to the verge of extinction. This study has been carried out to monitor vegetation dynamics and ecological status of wetlands of Koyna basin at spatial and temporal scale. This study has involved MODerate-resolution Imaging Spectroradiometer (MODIS) images of the year 2000, 2004 and 2008 on daily basis with spatial resolution of 1 km. The MODIS 16 days composite NDVI time series products of 250-m spatial resolution from year 2000 to 2008 has been utilized to monitor the ecological status of the wetlands. The European Nature Information System habitat classification map, meteorological data (precipitation, temperature) coupled with field data has been utilized to validate NDVI values of nine habitats in the wetlands. The time series analyses of NDVI data values have been correlated with the groundwater level depth from 1996 to 2004. The overall analysis has shown a declining trend of NDVI over the year 2000 to 2008, indicated a degraded wetland condition in span of 9 years.

Keywords Wetlands · MODIS · NDVI · Time series analysis · Turkey

Introduction

Wetlands are considered an integral part of the global ecosystem as they prevent or reduce severity of floods, feed groundwater aquifers and provide a unique habitat for flora and fauna (Mitsch and Gosselink 1993; Thakur 2010). Wetlands have dynamic hydrological characteristics frequently situated in complex terrain and are often difficult to monitor in situ. In addition, many wetlands are situated in remote locations with limited access and may cover extensive areas, as is the case with the wetlands of the Konya closed basin, Turkey. Earth Observation (EO) and Geographic Information System (GIS) is an effective tool not only for collection, storage, management and retrieval of a multitude of spatial and non-spatial data, but also for spatial analysis and integration of these data to derive useful outputs and modeling (Loaiciga et al. 1992; MacMillan and Splichal 2005), supporting the efficient management of wetland areas and contributing to improve the performance of its conservation convention (Jones et al. 2009).

Remote sensing has been used for wetland monitoring since the launch of ERTS-1, the first satellite of the Landsat

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MSS series, in the 1970s (Best and Moore 1979; Wickware 1978). In those days, the 80-m spatial resolution of Landsat MSS was often considered too crude for monitoring vegetation types (Gammon et al. 1979; Wickware and Howarth 1981). Today, the spatial resolution of optical satellite imagery, such as SPOT-4, SPOT-5 and Landsat TM (5–60 m), and very high-resolution optical sensors, such as IKONOS and Quickbird (between 2.5 and 4.0 m for the multispectral scenes and 0.6–1.0 m for the panchromatic scenes) make them ideal for capturing small features (Delory et al. 2010; Dial et al. 2003; Tong et al. 2010). The main advantage of remote-sensing-based monitoring of wetlands are as follows: it offers platform for data acquisition from remote location, synoptic view, at various resolution (spatial, spectral and temporal), easy to update and historical data and maps, time efficient and cost effective. Increases in resolution increased the cost and requires new methodology for processing and analysis. Unfortunately, increases in resolution capabilities also increase the costs of imagery collection (Töyrä and Pietroniro 2005). Moreover, it consists of medium spatial resolution, high spectral resolution and high temporal resolution. Therefore, many studies in past and current research are often utilizing the MODerate-resolution Imaging Spectroradiometer (MODIS) data for farmland study, vegetation indices analysis, land cover dynamics and estimation of flux variables. MODIS had been used for qualitative and quantitative studies on vegetation indices (Narasimhan and Stow 2010; Zhao et al. 2009). Ecological monitoring of wetlands can be done by quantification of vegetation dynamics (Ndirima 2007; Peters 2008). In this study, an attempt was made to quantify vegetation dynamics for various habitat types and inter-relating meteorological variables using integrated multi-temporal remote-sensing observation and field study at the local scale in this semi-arid region. Vegetation, both native and cultivated, strongly influences the environment and is influenced itself by the environment (Sabins 1996). Vegetation dynamics can be studied by long-term spatio-temporal analysis of Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and leaf area index (LAI). The NDVI relies on the absorption of red radiation by chlorophyll and other leaf pigments, and the strong scattering of near-infrared radiation by foliage. Consequently, red reflectance tends to decrease as the amount of green vegetation in a pixel increases. At the same time, the structural properties of a denser canopy (e.g., increasing leaf area index and crown coverage) cause an increase in near-infrared reflectance. The interpretation of NDVI in terms of structural properties of vegetation (e.g., LAI) and its photosynthetic activity (i.e., the fraction of absorbed photosynthetically active radiation) are supported by empirical studies, as well as simulations with physically based radiative transfer models (Baret and Guyot 1991; Guyot et al. 1989). Through these vegetation indices, it is possible to assess many biogeochemical parameters (Gitelson et al. 2006), like land cover, forest stand age, canopy height, LAI (Yi et al. 2008), Net Primary Production (NPP), Net Ecosystem Production (NEP), biomass (Muukkonen and Heiskanen 2007), chlorophyll concentration, photosynthetic efficiency, leaf water content, carbon and water balances, foliar nitrogen, crop yield desertification monitoring (Yan et al. 2005) and methane emission modeling (Agarwal and Garg 2009), all considered in various models for understanding wetland ecosystems.

In our study, we used traditional method for monitoring of vegetation in the wetlands area. The NDVI is a numerical indicator that represents the fraction of the photosynthetically active radiation absorbed by vegetation (Breunig et al. 2010; Gu et al. 2009; Shoshany et al. 1996). To determine the density of green vegetation in the study area, distinct wavelengths of visible and near-infrared sunlight reflected by the plants should be observed. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 μm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 μm). The more leaves a plant has, the more these wavelengths of light are affected. NDVI is given by:

$$\mathrm{NDVI} = \frac{(\alpha_{0.86\mu m} - \alpha_{0.67\mu m})}{(\alpha_{0.86\mu m} + \alpha_{0.67\mu m})} \quad (1)$$

where $\alpha_{0.67\ \mu\mathrm{m}}$ and $\alpha_{0.86\ \mu\mathrm{m}}$ stand for the atmospherically corrected spectral reflectance measurements acquired in the red and near-infrared regions, respectively. These spectral reflectances are ratios of the reflected over the incoming radiation in each spectral band individually; hence, they take on values between 0.0 and 1.0. By design, the NDVI itself thus varies between -1 and $+1$. The NDVI values were compared with rainfall data of the period of study, as there is positive correlation between NDVI and rainfall (Asefa et al. 2004; du Plessis 1999; Kileshye Onema and Taigbenu 2009). The present study focused on the following objectives: (1) to study potentiality and capabilities of MODIS data in spatial and temporal analysis of wetlands, (2) to study vegetation dynamics utilizing time series of NDVI to monitor ecological status of the wetlands and (3) to study the relationship of NDVI with rainfall and groundwater in the wetlands.

Study area

The wetland, near Lake Tuz, is located between 38°11′ and 39°18′N latitudes and 32°15′–34°15′E longitudes in the

Konya closed basin to the south from Ankara in the heart of Turkey (Fig. 1). The wetland is of an irregular shape having total area of 7,651 km^2 situated at an elevation of 905 m above mean sea level (Gökmen et al. 2009).

Tuz Lake was declared as an area of natural importance in 1992 and declared as a Special Environmental Protection Area (SEPA) in 2000. European Nature Information System (EUNIS) habitat classification was carried out by Environmental Protection Agency for Special Area (EPASA) of Turkey for the determination of biodiversity in TUZ Lake SEPA using satellite images of 1987 and 2007 and field surveys. The EUNIS habitat classification shown in Fig. 1 has short codes, and the short codes are described in Table 1 (EEA 2009).

Halophytic and simple steppes are the dominant vegetation in the study area. The common feature of these steppes is that there is always at least one saline water body in the central part of steppe areas. In this area, 21 different halophytic steppe plants specific to the area are available and out of which eleven species of this population are under risk. The rest of the area out of the saline steppes around saline lakes is covered with xerophytic plants (Tektas 2007). Most of the land in the area has been amended to be cultivated and this created mosaic scenery,

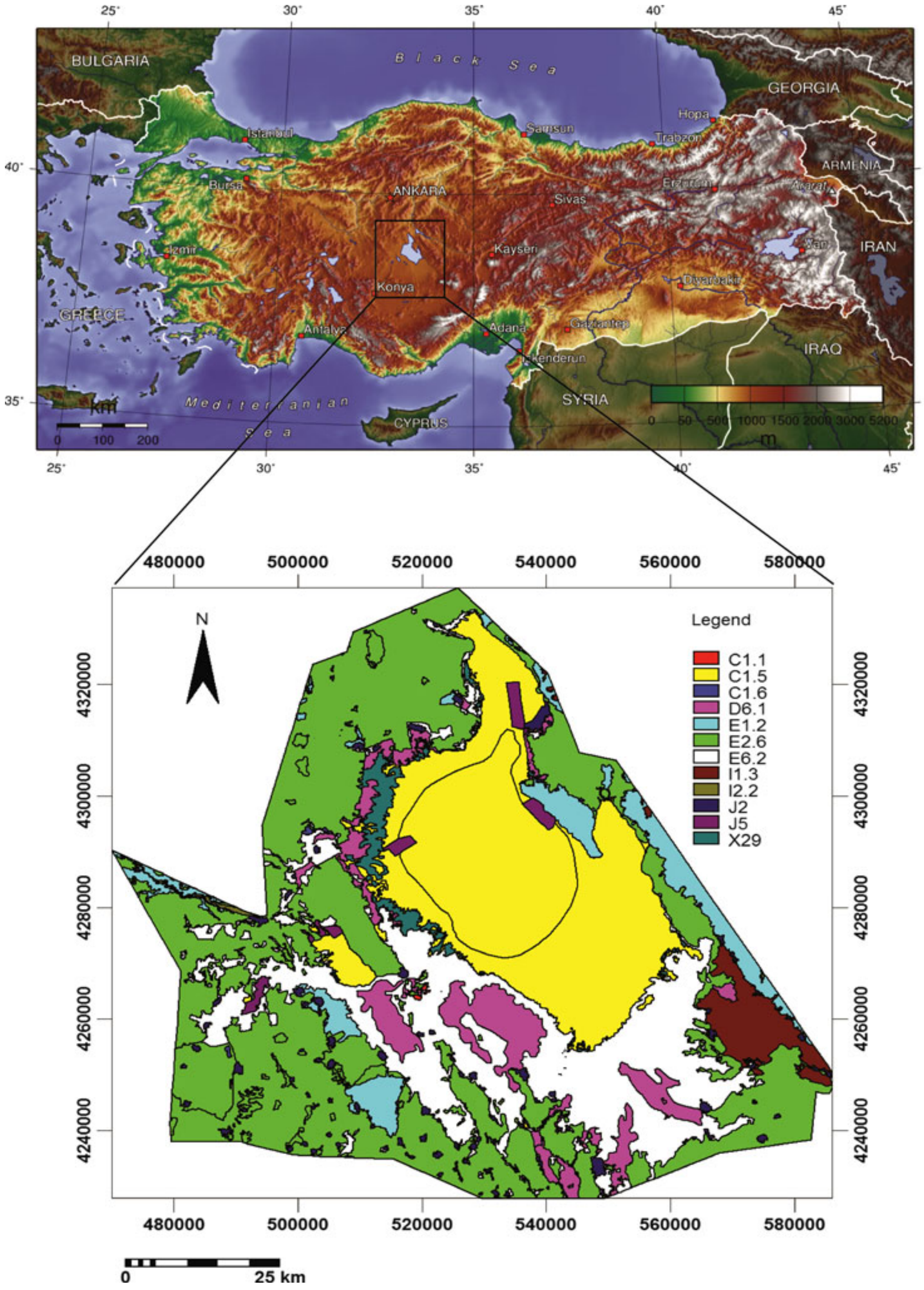


Fig. 1 Location of wetlands around Tuz Lake in Konya closed basin, Turkey. (Shape file source: Environmental Protection Agency for Special Areas (EPASA))

Table 1 Codes of various habitat types in the wetlands of Konya closed basin

Codes	Habitat types
C1.1	Permanent oligotrophic lakes, ponds and pools
C1.5	Permanent inland saline and brackish lakes, ponds and pools
C1.6	Temporary lakes, ponds and pools
D6.1	Inland salt marshes
E1.2	Perennial calcareous grassland and basic steppes
E2.6	Agriculturally improved, re-seeded and heavily fertilized grassland, including sports fields and grass lawns
E6.2	Continental inland salt steppes
I1.3	Arable land with unmixed crops grown by low-intensity agricultural methods
I2.2	Small-scale ornamental and domestic garden areas
J2	Low-density buildings
J5	Highly artificial man-made waters and associated structures
X29	Salt lake islands

simple steppe areas between dry and wet agricultural fields. These steppes can also be considered as meadows because the farmers use these steppes to graze their animals. Eight plant sub-communities belonging three communities, 39 endemic species, four threatened species and four local endemics—not scientifically known before—of the flora of the Tuz Lake have been identified by Environmental Protection Agency for Special Areas (EPASA) (Tektas 2007). Plant species such as Kochia *prostrata,* Leymus *cappadocicus*, Agropyron *cristatum*, Chyrosopogon *gryllus* and Puccinellia *distants* with economical potential are also present in this area. Figure 2 is photograph of salt pits and bowls in the inlands salt marshes habitat type (D6.1) in the wetlands of study interest.

Data used

Remotely sensed MODIS images (daily temporal resolution, 1-km spatial resolution) for the year 2000, 2004 and 2008; MODIS NDVI products 16 days composite (MOD 13: 250 m resolution) for the year 2000–2008, GIS data as EUNIS habitat classification map (Source: EPASA); thematic data as meteorology data including precipitation, temperature (Source: Turkish State Meteorology Service) and field data in the form of field visit has been carried out to estimate NDVI values for nine habitats in the wetlands. The above estimated NDVI was clumped with meteorological data to analyze the ecological variation in the study area. The monthly depth to groundwater level from 1996 to 2004 (9 years) was taken from two observation wells in Çaldere and Çengilti, which are located at southwestern part of study area.

Research method

This study explored the possibility of monitoring the spatial distribution of vegetation based on MODIS data,

Fig. 2 Salt pits and bowls in the wetlands, Konya closed basin, Turkey

investigates temporal dynamics at local scale of nine habitats type in wetland using MODIS-derived vegetation indices and also explored the relationship between observed dynamics and environmental variables. The degradation of natural vegetation has been indicated by the yearly mean NDVI time series data for some distinctive units. The flow chart of main steps for the analysis of vegetation dynamics to meet the research objectives is shown in Fig. 3.

The NDVI time series from the year 2000 to 2008 of three habitat types namely D6.1, E1.2 and E6.2 have been produced from MODIS 16-day NDVI products having approx. 250 m × 250 m spatial resolutions, which enabled us to identify NDVI trends of these natural wetland habitat types. NDVI estimation using MODIS raw data has been performed for six habitat types namely C1.1, C1.6, E2.6, I1.3, I2.2 and J2 habitat type of the wetlands for the year 2000, 2004 and 2008. NDVI was estimated from MODIS band 1 and band 2 using Eq. 1. In order to validate the result of ecological monitoring in the study area, the time series of NDVI was compared with groundwater level in the study area as these two variables are highly correlated.

MODIS 16-day NDVI products

The MODIS (Terra) 16-day composite NDVI Level 3 data set for the 9-year period from year 2000 to 2008 was converted from the Hierarchical Data Format (HDF) having file value: 0–32767 into GeoTIFF format having file values 0–1 by using MODIS Swath Reprojection Tool. The estimation of monthly mean NDVI for D6.1, E1.2 and E6.2 habitat was calculated from MODIS NDVI Level 3 data with the shape file of the EUNIS habitat classification by using ArcGIS 9.3. Time series data of monthly mean NDVI and annual mean NDVI (Excluding dataset of January, February, March, November and December because of extensive cloud cover in the region) was organized to examine the spatio-temporal dynamics of vegetation.

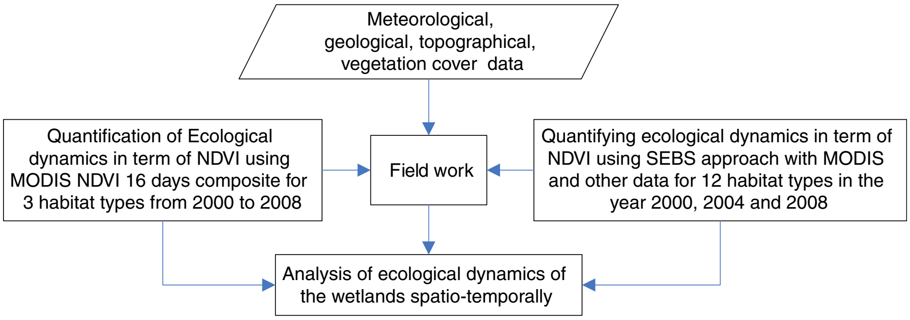
MODIS raw data

Cloud-free, good-quality, summer time MODIS images were acquired from National Aeronautics and Space Administration (NASA) web site (http://www.modis.gsfc.nasa.gov/data/). The MODIS Swath Reprojection Tool (ModisSwathTool) was used to process MODIS level-1 product having HDF format into the GeoTIFF format ready for ILWIS importing. For Latitude/Longitude of the spatial subset field, upper left corner 39.5°N latitude and 31.0°E longitude and lower right corner 36.8°N latitude and 35.1°E longitude were given for the study area of the Konya, Turkey. During reprojection, the data were resampled using the nearest neighbor methods in such a way that the pixel sizes in both x and y direction, 0.01 was given which corresponds to 1 km pixel size. In ILWIS, files were imported one by one via Geospatial Data Abstraction Library (GDAL). To import geolocation files, solar zenith, solar azimuth, sensor zenith and sensor azimuth, similar process was followed. The imported solar and satellite angle maps was re-scaled by multiplying the maps by 0.01 in map calculation function in ILWIS. The imported MODIS channels were converted from digital number into radiance and reflectance. The calibration coefficients consist of a scale and offset that are available in the HDF header file of the original MODIS image for each individual band was used. In case of visible bands, band 1–2, the calibration coefficient information, i.e., radiance and reflectance scales were taken from the file “EV_250_Aggr1km_RefSB”. The offsets are zero in these cases. The raw MODIS visible bands data were converted into radiance and reflectance by using “raw to reflectance (MODIS)” tools in ILWIS. The scale and offset values for radiance correction, which can be read from HDFView software was used in this conversation.

Atmospheric correction of the MODIS satellite images

Atmospheric correction converts the top of the atmosphere signal to the surface reflectance as a result the surface

Fig. 3 Flow chart for analysis of vegetation dynamics in the study area



spectral reflectance is estimated for each band as it would have been measured at ground level. SMAC (Simplified Method for Atmospheric Corrections) tool was used for atmospheric correction of images having solar zenith less than 60° and/or satellite zenith angle less than 50°. SMAC processing required data for total amounts of ozone and water vapor in the atmosphere as in the aerosol optical depth and surface atmospheric pressure. Data of Aerosol Optical Depth (AOD) for nearest station, HIS-METU-ERDEMLI station, was obtained from AErosol RObotic NETwork (AERONET) web site (http://www.aeronet.gsfc.nasa.gov) for following wavelengths: 340, 380, 440, 500, 675, 870 and 1,020 nm. AOD at 550 nm wavelengths was calculated by graphically plotting AOD of these wavelengths. The data of water vapor content for particular time of satellite passage of the particular day were also retrieved from AERONET web site. Status of near-real-time measurements of ozone (expressed in Dobson Units) in the atmosphere was obtained from NASA website (http://www.toms.gsfc.nasa.gov/ozone/ozone_v8.html). The surface pressure (expressed in hectopascal or millibars) in the study area was obtained from metrological data set. Beside this, solar zenith angle map, solar azimuth angle map, sensor zenith angle map and sensor azimuth angle map were used as inputs.

The NDVI values were calculated using the Eq. 1 from atmospherically corrected MODIS band 1 and band 2. In the second stage, fieldwork was carried in the wetlands of the Konya closed basin, Turkey, for NDVI ground truths. The ground control points were collected, using Garmin made hand-held GPS.

Statistical analysis

Statistical analysis involves correlation analysis, which is use to describe the degree of relationship between two variables. The coefficient of correlation (r) is a measure of the strength of the straight-line or linear relationship between two variables. The correlation coefficient takes on values ranging between +1 and −1. +1 indicates a perfectly positive linear relationship, while 0 and −1 indicates no or perfectly negative correlation, respectively. The equation for r computation is (Johnson and Wichern 2002):

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}} \tag{2}$$

where x and y are the variables chosen for the analysis and n is the number of pairs of data. All data were statistically analyzed by SPSS 17.0 software.

Results and discussion

Although there are many hydrological components in the water cycle of wetlands, to understand ecological dynamics in wetlands ecosystem, the time series result of NDVI obtained from remotely sensed data was compared with field-based observation of groundwater table in the study area.

Temporal analysis of NDVI of D6.1, E1.2 and E6.2 habitat

Figure 4 is graphical plot of annual mean NDVI and annual rainfall from year 2000 to 2008. The annual mean NDVI represents average of annual mean of NDVI of D6.1, E1.2 and E6.2 habitat types in the wetlands.

The mean NDVI value of these habitat types was 0.222 with high total annual rainfall 335 mm in the year 2000 and 0.232 mm and 337 mm, respectively, in the year 2003. The NDVI value observed in 2003 was highest during the overall study period. In the year 2005, the mean NDVI value was 0.213, which was below average value; whereas the total yearly rainfall recorded as 330 mm, higher than 2008. Similarly in the year 2001, mean NDVI value was 0.197, observed as lowest one among the overall study period. The total yearly rainfall in the year 2001 was 238.40 mm, which was lower than 2000, 2003 and 2005 but higher than 2008. In the year of 2008, the mean NDVI value is 0.198, which was below average, and the yearly total rainfall was 218 mm, which was the lowest rainfall recorded in all the observed datasets in the study period. The results analysis revealed that NDVI value was high in the year of high rainfall, and this demonstrates the positive correlation between the NDVI and rainfall.

Spatio-temporal analysis of NDVI of D6.1, E1.2 and E6.2 habitat

There are three major vegetation habitat types has been recorded in the study area, numbered as D6.1, E1.2 and E6.2 classes, and are inland salt marshes; perennial calcareous grassland and basic steppes; and continental inland salt steppes, respectively. The halophytes growing normally in saline inland ecosystems (D6.1 habitat type) showed a number of adaptive traits expressed at various levels of organization, which allow them to germinate, grow and achieve their complete cycle of development under water deficit harsh conditions but still NDVI value of this habitat type is declining during the overall study period from the year 2000 to 2008. This temporal declination in NDVI value reflects that there was decrease in intensity

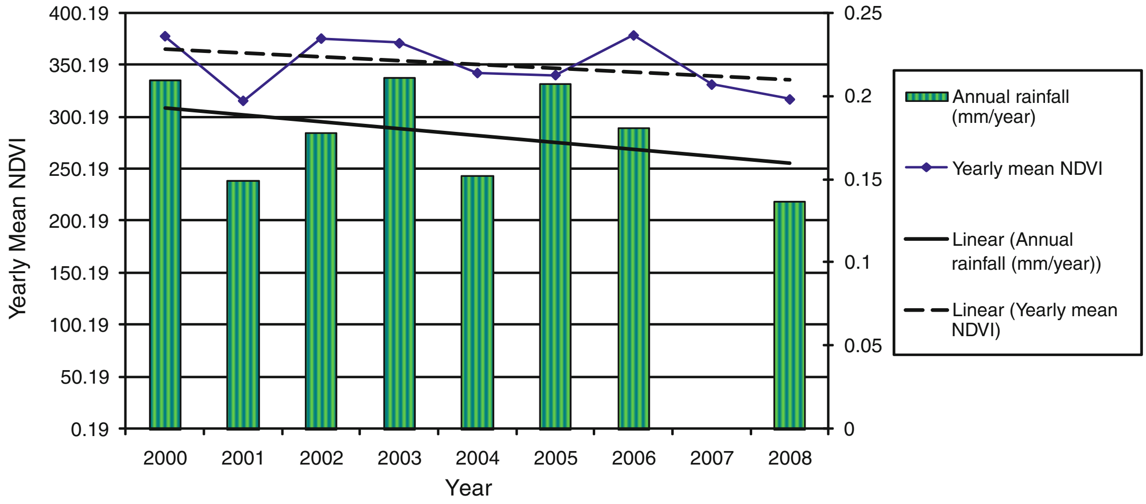


Fig. 4 Annual mean NDVI and annual rainfall in the wetlands

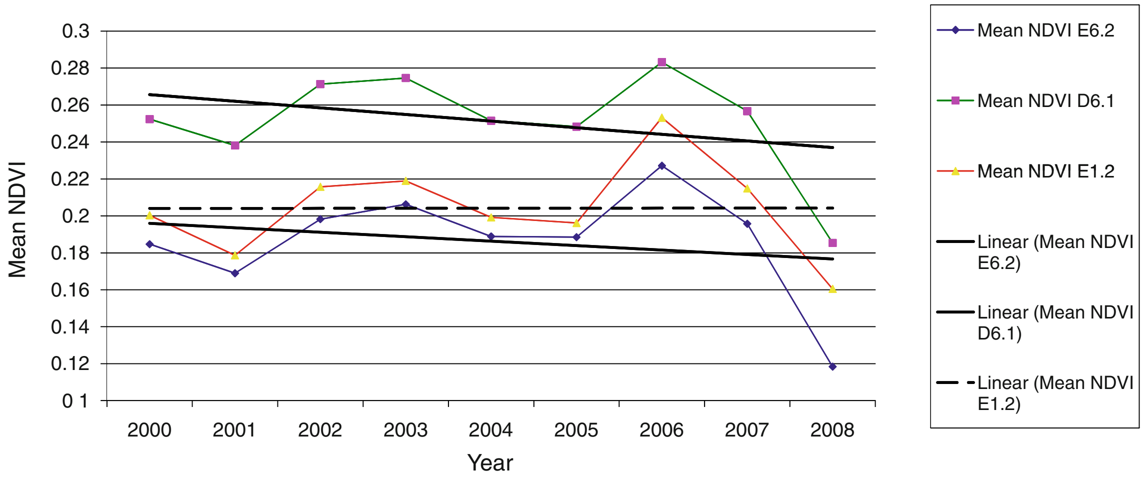


Fig. 5 Annual mean NDVI of D6.1, E1.2 and E6.2 habitat types from the year 2000 to 2008

and frequency of rainfall that could lead to drought as a natural hazard in the area of the D6.1 habitat type. Similar results have seen in various other studies also in different part of the world (Cui et al. 2009; Durduran 2010; Peters et al. 2002; Zhou et al. 2008). On the other hand, the E1.2 habitat type is perennial grassland, often nutrient poor and species rich, on calcareous and other basic soils of the nemoral and steppe zones and of adjacent parts of the sub-boreal and sub-Mediterranean zones had normal NDVI value, which does not fluctuate during the study period. The NDVI fluctuation of these habitat types is shown in the Fig. 5. The E6.2 habitat type has salt steppes and their associated salt-tolerant herbaceous communities. However, the NDVI value of E6.2 habitat type showed a continuous decline from 2000 to 2008. It may ascribe because of declination of soil moisture availability in the habitat.

During the entire study period, no significant trend change in the NDVI value for the E1.2 habitat type has been observed, which insights that there was enough amount of water available irrespective of decreasing rainfall, as there exist positive correlation between NDVI value and the availability of water for the vegetation. The alternative source of water in this area could be ground water recharge as many upwelling springs were observed during field visit. The annual mean NDVI values of these habitat types from the year 2000 to 2008 and annual rainfall at the nearest rainfall station (Table 2) show positive correlation and overall declining trend from the year 2000 to 2008.

Figure 6 is a graphical plot of monthly mean NDVI of various habitat types. The highest fluctuation in NDVI was observed in inland salt marshes habitat type, the D6.1, with maximum value during summer and minimum during winter months.

However, the NDVI value of continental inland salt steppes habitat (E6.2) showed a smoother values during summer months and very low value during winter months.

Table 2 Annual mean NDVI and annual rainfall in the study area

Year	Annual mean NDVI[a]				Annual rainfall (mm/year)
	E6.2	D6.1	E1.2	Average in these wetlands	
2000	0.19	0.25	0.20	0.24	335.30
2001	0.17	0.24	0.18	0.20	238.40
2002	0.20	0.27	0.22	0.24	283.60
2003	0.21	0.28	0.22	0.23	337.10
2004	0.19	0.25	0.20	0.21	242.90
2005	0.19	0.25	0.20	0.21	330.70
2006	0.23	0.28	0.25	0.24	288.40
2007	0.20	0.26	0.22	0.21	No data
2008	0.12	0.19	0.16	0.20	218.00

[a] Nov, Dec, Jan, Feb and Mar are not included because of poor data coverage

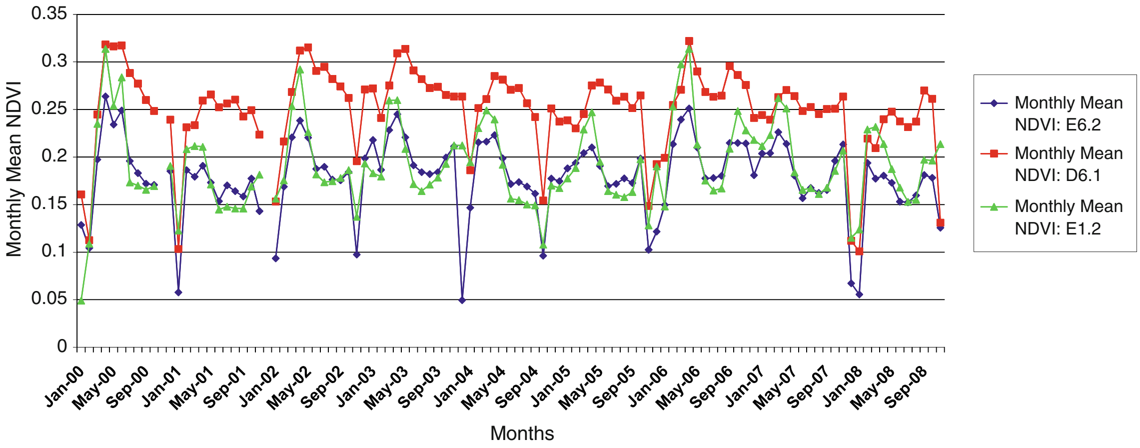


Fig. 6 Monthly mean NDVI of E6.2, D6.1, E1.2 habitat types

Whereas, the NDVI value for perennial calcareous grassland and basic steppes (E1.2) showed a nominal fluctuations during overall the study periods, i.e., 2000–2008 that ascribe regular availability of soil moisture for the vegetations in this habitat.

Spatio-temporal analysis of NDVI of C1.1, C1.6, E2.6, I1.3, I2.2 and J2

In the same study area, six more vegetation habitat types, C1.1, C1.6, E2.6, I1.3, I2.2 and J2 were studied which are permanent oligotrophic lakes, temporary lakes, agriculturally improved-reseeded and heavily fertilized grasslands, arable land with unmixed crops grown by low-intensity agricultural methods, small-scale ornamental and domestic garden area, and highly artificial man-made water bodies, respectively (Hjortsø et al. 2006). The annual mean NDVI of the oligotrophic lake habitat (C1.1), having low nitrogen and phosphorus content, mostly acid (pH 4–6), in this study area, in the year 2000, 2004 and 2008 are 0.22, 0.21 and 0.19 and has declining trend (Fig. 7). Similarly, temporary lakes habitat (C1.6), are irregularly distributed in the study area, has declining trend of annual mean NDVI during the year 2000, 2004 and 2008 (Fig. 7). Whereas in case of agriculturally improved re-seeded and heavily fertilized grassland habitat, including sports fields and grass lawns (E2.6) have same annual mean NDVI in the year 2000 and 2008 although there was a high rainfall in the year 2000. The annual mean NDVI this habitat in the year 2004 was higher than the year 2000 and 2008 (Fig. 7). This habitat type covers large area and is more influenced by human activities. In addition, the arable land habitat with unmixed crops grown by low-intensity agricultural methods (I1.3), small-scale ornamental and domestic garden areas (I2.2) and less dense semi-urbanized built up area and artificially vegetated area (J2) are having higher annual mean NDVI in the year 2004 and lower in the year 2000 and 2008 (Fig. 8). Although the annual total rainfall in these areas was higher in the year 2000 than the year 2008, the relative trend of annual mean NDVI showed a declining trend. Similar type of human-induced degradation of the wetlands has also seen in other studies of wetlands in Turkey (Çal kan 2008).

Fig. 7 Annual mean NDVI of C1.1, C1.6 and E2.6 habitat types

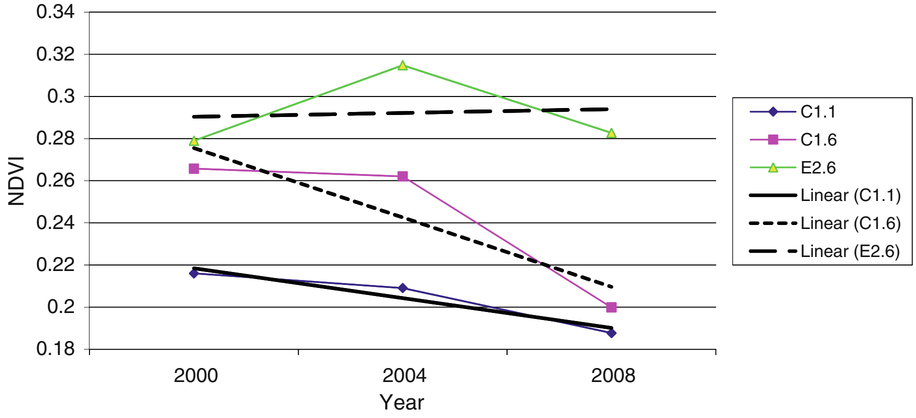
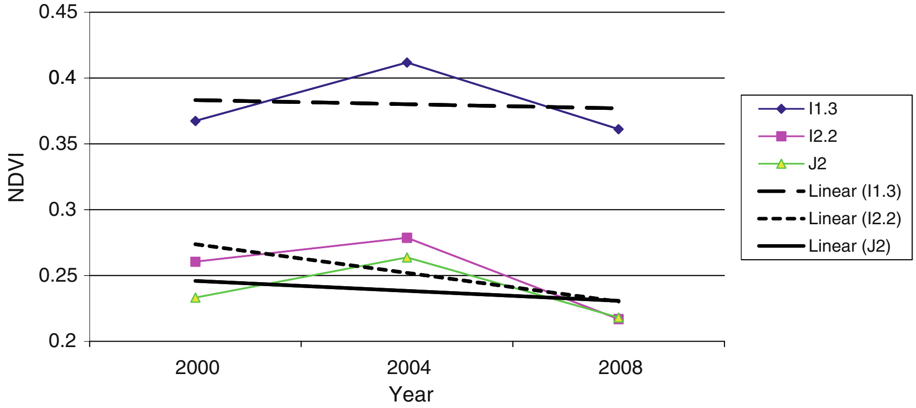


Fig. 8 Annual Mean NDVI of I1.3, I2.2 and J2 habitat types



The continuous decline in groundwater levels has been proved by shrinking or drying up of wetlands, such as the Tuz lake, which is believed to be mostly groundwater fed (Obioma Nze 2010; Özkaymak 2009). The monthly groundwater level records from 1996 to 2004 (9 years) illustrate the spatio-temporal variation in groundwater levels of two wells located in Çaldere and Çengilti, Konya (Fig. 9). Further assessment of this figure showed that there was drop of about 3.16 m and 10.57 m in the groundwater levels of these two wells located in Çaldere and Çengilti, occurred within the span of 9 years.

In order to validate ecological dynamics, the time series result of NDVI derived from remotely sensed data has been correlated with field-based observation of groundwater level of two wells in the study area. This declining response of natural vegetation can be dependent up depleting of groundwater feeding to the wetlands (AFCEE 2006). In the low precipitation environment of semi-arid region, the vegetation growth has close relationship with groundwater in the wetlands of Konya closed basin, Turkey. The above findings were further supported by the correlation coefficients analysis of the NDVI with groundwater level depth. The correlation coefficients between remotely sensed annual mean NDVI and field-based observation of annual mean groundwater level in the two wells located in Çaldere and Çengilti, Konya are 0.31 and 0.74, respectively, (Fig. 10) showed a higher degree of relationship with Cengilti as compared with Caldere, and may be due to variation in terrain properties.

Whereas a study by Jin et al. (2007) showed that the lower the depth of water from the surface, better vegetation grows (Kumar et al. 2010). The declination of groundwater level depth during the span of 9-year period strongly validates the temporal declination of vegetation growth.

Conclusion

The freely available MODIS data are better option than commercial data at coarse resolution along with higher swath for the mapping and monitoring of wetlands, which could facilitate in the pragmatic policymaking. We found through the results that a significant positive relationship exists between variations in habitat types based on NDVI analysis. The above finding suggests that remotely sensed

Fig. 9 Monthly depths to water table variability plot of two observation wells (*Source*: DSI (State hydraulic Works of Turkey))

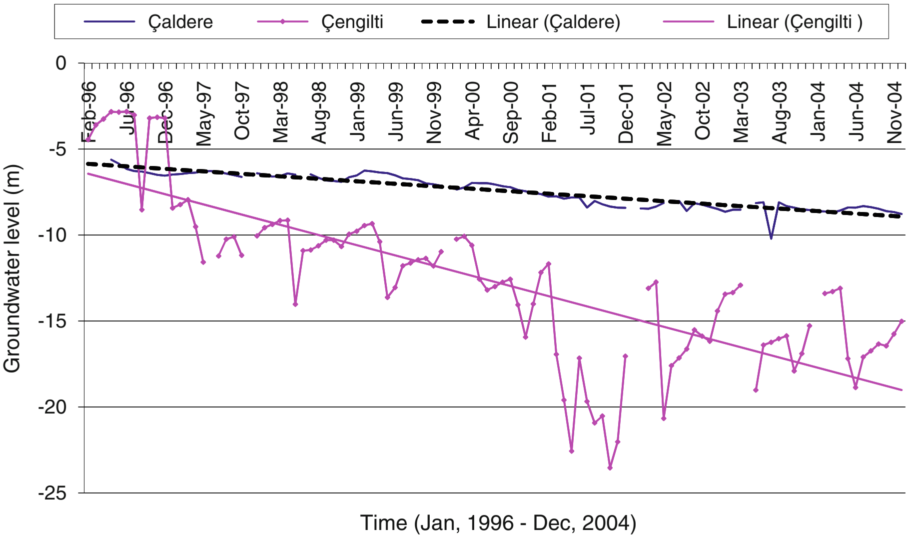
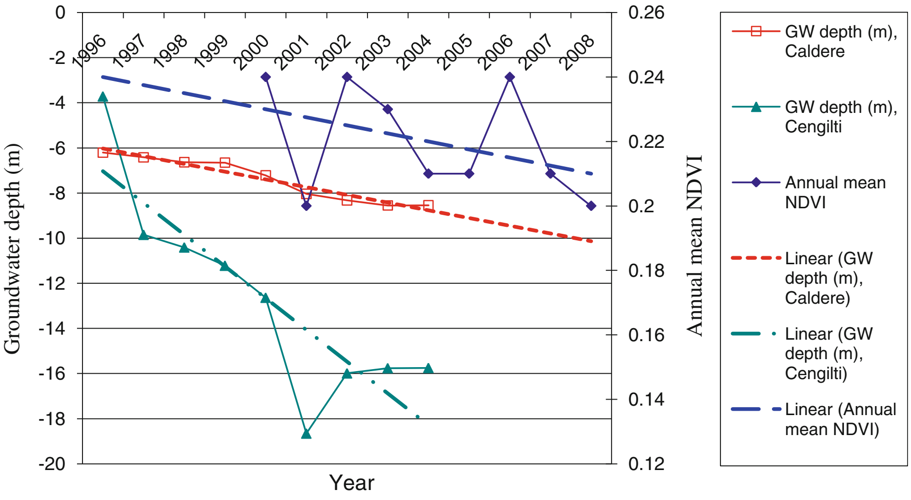


Fig. 10 Declination trend of groundwater elevation depth of wells in Çaldere and Çengilti, Konya, and over all average annual NDVI of the study area



NDVI is valuable for monitoring habitats type changes at both local and regional scales. The average NDVI value of these wetlands showed a declining trend from the year 2000 to 2008. All the habitat types of the wetlands except E2.6 habitat type showed declination in trend with observed daily, monthly and annual mean NDVI. Consequently, this temporal declination in NDVI and annual rainfall values will result in drought situation in the wetlands at regional as well as local scales. The continuous decline in groundwater levels from 2000 to 2008 (9 years), shrinking or drying up of wetlands, illustrate the spatio-temporal variability of groundwater levels. The monthly groundwater level records from two wells located in Çaldere and Çengilti, Konya, Turkey, showing a drastic decrease in groundwater level within a span of 9 years indicates a direct relationship between NDVI, wetland ecology and groundwater levels. This study strengthen the relationship between habitat type and NDVI values, could provide confidence to policy makers, ecologists and hydrologist for using remote-sensing techniques in habitat types analysis, desertification process analysis and wetland conservation. Moreover, NDVI values are relative but not absolute; therefore, it may be affected by other factors apart from natural disturbances. So, more study in this field is require to conserve the wetlands focused on degree of anthropogenic disturbance, the accuracy of mapping, habitat type, and quantification of impact of climate change and sustainability in the extreme situations. However, our findings provide a useful point in seeking general relationships between habitat types; earth observations derived NDVI, groundwater level and climatic condition for reconnaissance wetland monitoring.

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