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Determination of land productivity index based on parametric approach using GIS technique

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Abstract

The land productive capacity can be evaluated directly or indirectly. Direct evaluations are carried out in the field, greenhouses or laboratory by means of some experiments under given climatic and management conditions. Indirect evaluations consist basically in developing and applying models of varying complexity, thereby attempting to estimate land productivity. The main objective of this research was to determine land productivity index based on parametric approach using GIS. This study was carried out in Çetinkaya district located on Bafra Delta Plain. The study area covers about 1762.4 ha. After analysing and evaluating topographic, soil physical and chemical properties, result map was generated for land productivity index (LPI) by means of GIS. After LPI taking into rating of soil and topographic parameters was calculated using square root formula, productivity classification was determined for each land mapping unit. According to results, while most of the study area's land productivity (45.4%-800.0 ha) consist of excellent and good classes (I and II) in terms of agricultural uses, it was found that 19.7% (346.6 ha) of study area has average (III), 25.1% (441.6) of it has poor (IV) and rest of it (9.8%) has extremely poor or nil (V).

Keywords: Land productivity, parametric evaluation, GIS

Introduction

Agriculture is one of the world's most important activities supporting human life. From the beginning of the civilization man has used the land resources to satisfy his needs. The land resources regeneration is very slow while the population growth is very fast, leading to an unbalance. Potential land use assessment is likely to be the prediction of land potential for productive land use types. This case is great important in guiding decisions on land uses in terms of potential and conserving natural resources for future generations. Therefore, careful planning of the use of land resources is based on land evaluation, which is the process of assessing the suitability of land for alternative land uses (Fresco et al, 1994).

Land productivity capacity or land quality is a comprehension, at the same time a precise concept in terms of agricultural activities. It is defined as a measure of capability of land to perform specific functions (Devi and Kumar, 2008). Undoubtedly, one of the ways to provide food is to increase production in area and to use the land with respect to its potentiality in an appropriate way. Pieri et al. 1995 and Dengiz et al., 2009 also reported that land quality has been defined as "the condition and capacity of land, including its soil, climate, topography and biological properties, for purpose of production, conservation, and environmental management".

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The land productive capacity can be evaluated directly or indirectly. Direct evaluations are carried out in the field, greenhouses or laboratory by means of some experiments under given climatic and management conditions. Indirect evaluations consist basically in developing and applying models of varying complexity, thereby attempting to estimate land productivity (Delgado and Lopez, 1998; Dengiz, 2007). Eswaran et al., (2003) made use of Geographic Information System to assess and monitor quality of land. They combined the soil and climate variables as these influence agricultural productivity

The investigation focused on determination of land productivity index based on parametric approach using GIS in selected areas.

Material and Method

Field description

This study was carried out in Samsun-Bafra delta plain and near district. The Bafra Plain found in the Kızılırmak Delta and located in the central Black Sea region of Turkey (Figure 1). The study area is far 30 km from west of the Samsun province (4602-4609km N- 234-242km E UTM), It covers 1762.4 ha and its lies at an elevation from sea level 0-150 m.

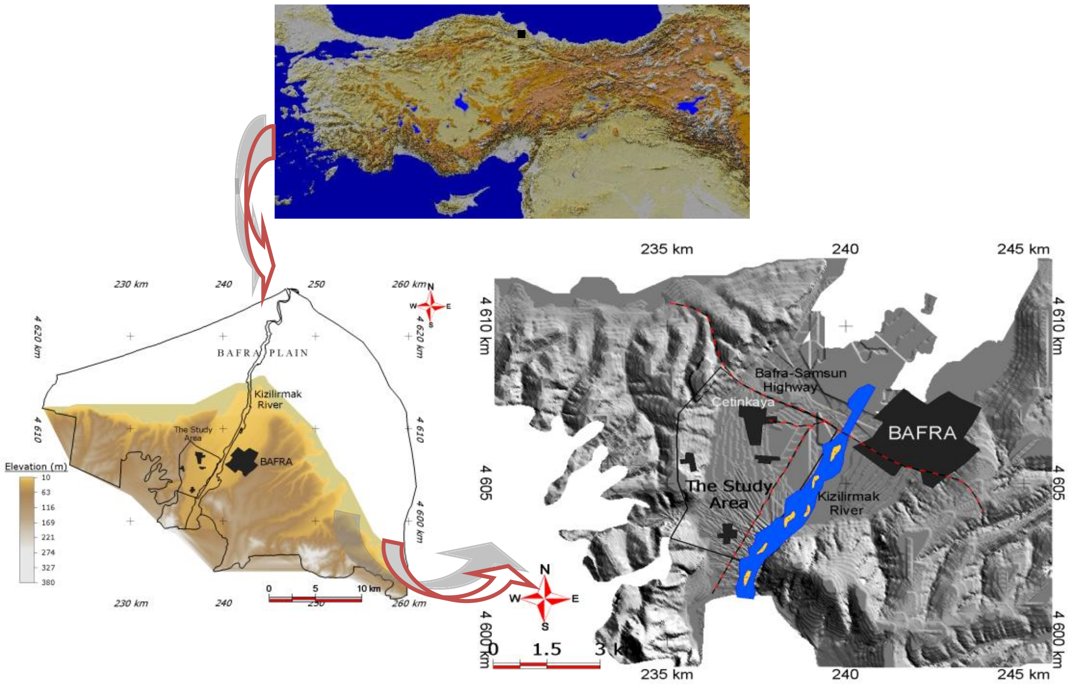

Figure 1. Location map of the study area

The current climate in the region is semi-humid. The summers are warmer than winters (the average temperature in July is 22.2 and in January is 6.9 °C). The mean annual temperature, rainfall and evaporation are 13.6 ºC, 764.3 mm and 726.7 mm respectively. According to Soil Taxonomy (1999), the study site has mesic soil temperature regime and ustic moisture regime. The study area has two major physiographic units. Most of the study area is flat and slightly sloped (0.0-2.0%) on alluvial land and second unit is hilly and moderately to severe sloped (%3-20). The majority of research area’s soils were classified as Vertisol, Inceptisol and Entisol in Soil Taxonomy (1999). Flat land of the study area has been under intensive agricultural activities. Rice, wheat, maize, pepper, watermelon, cucumber and tomato with sprinkler and furrow irrigations in the summer, and cabbage and leek in the winter have been produced in the study area.

Data analysis

A parametric method for land evaluation has been proposed by Riquier et al. (1970). They claim that limitations are a negative and complex concept and that present and future capability are better expressed in terms of productivity. The system avoids economic and sociological considerations which lie outside the province of the soil scientist. Land productivity or yields, moreover, provide the best grounds for understanding between the soil scientist and economist (Ranst, 1991).

The system suggests the calculation of a productivity index considering ten factors as determining land productivity. Moisture (H), Drainage (D), Soil depth (P), Texture/Structure (T), Base saturation (N), Soluble salt concentration (S), Organic matter (O), Mineral exchange capacity (A) and Mineral reserve (M). These characteristics concern are rated and used to calculate for the productivity index (LPI) according to a complex square root system as given following the formula 1:

$$LPI = Rmax * \sqrt{\frac{H}{100} * \frac{D}{100} * \frac{P}{100} * \frac{T}{100} * \frac{N}{100} * \frac{O}{100} * \frac{A}{100} * \frac{M}{100} * \frac{E}{100} * \frac{S}{100}} \quad [1]$$

Rmax: Avarage maximum rating,
H, D, P.....: Other rating

Each factor is rated on a scale from 0 to 100 and the resultant index of productivity, also lying between 0 and 100, is set against a scale placing the soil in one or other of five productivity classes (Table 1).

Table 1. Land productivity classes

Land Productivity index	Definition	Symbol
65-100	Excellent	I
35-64	Good	II
20-34	Average	III
8-19	Poor	IV
0-7	Extremely poor or nil	V

Each of land and soil and land characteristics with associated attribute data are digitally encoded in a GIS database to eventually generate ten thematic layers. The diagnostic factors of each thematic layer were assigned values of factor rating identified in Table 2, 3, 4, 5, and 6.

Table 2. Definition of soil moisture and organic matter

Soil Moisture Content (H)		**Organic matter in A1 horizon (O)**	
H1	Rooting zone below wilting point all the year round	O1	Very little organic matter, less than 1%
H2	Rooting zone below wilting point for 9 to 11 months of the year H2a: 11, H2b: 10, H2c: 9 months,	O2	Little organic matter, 1-2%
H3	Rooting zone below wilting point for 6 to 8 months of the year H3a:8, H3b: 7, H3c: 6 months,	O3	Average organic matter content, 2-5%
H4	Rooting zone below wilting point for 3 to 5 months of the year H4a:5, H4b: 4, H4c: 3 months,	O4	High organic matter content, over 5 %
H5	Rooting zone above wilting point and below field capacity for most of the year	O5	Very high content but C/N over 25

Table 3. Definition of soil depth and slope

Soil depth (P)		**Slope (E)**	
P1	Rock outcrops with no soil cover or very shallow cover	E1	Flat 0-2%
P2	Very shallow soil, < 30 cm	E2	Slightly 2-6%
P3	Shallow soil, 30-60 cm	E3	Moderately 6-12%
P4	Fairly deep soil, 60-90 cm	E4	High 12-20%
P5	Deep soil 90-120 cm	E5	Very high 20-30%
P6	Very deep soil > 120 cm	E6	Steep 30% +

Table 4. Definition of soil drainage and reserves weatherable mineral

Drainage (D)		**Reserves of Weatherable mineral in B horizon (M)**	
D1a	Marked waterlogging, water table almost reaches the surface all year round	M1	Reserves very low to nil
D1b	Soil flooded for 2 to 4 months of year	M2	Reserves fair
D2a	Moderate waterlogging, water table being sufficiently close to the surface to harm deep rooting plants	M2a	Minerals derives from sands, sandy material or ironstone
		M2b	Minerals derives from acid rock
D2b	Total waterlogging of profile for 8 days to 2 months	M2c	Minerals derived basic or calcareous rocks
D3a	Good drainage, water table sufficiently low not to impede crop growing	M3	Reserves large
D3b	Waterlogging for brief period (flooding), less than 8 days each time.	M3a	Sands, sandy materials or ironstone
D4	Well drained soil, deep water table; no waterlogging of soil profile	M3b	Acid rock
		M3c	Basic or calcareous rocks

Table 5. Definition of soil texture and structure of root zone and base saturation and pH

Texture and Structure of Root Zone (T)		Base Saturation and pH (1:1) of A Horizon (N)	
T1	Pebbly, stony or gravelly soil	N1	B.S <15 % pH: 3.5-4.5
T1a	Pebbly, stony or gravelly > 60 % by weight	N2	B.S 15-35 % pH: 4.5-5.0
T1b	Pebbly, stony or gravelly from 40 to 60 %	N3	B.S 35-50 % pH: 5.0-6.0
T1c	Pebbly, stony from 20 to 40 %	N4	B.S 50-75 % pH: 6.0-7.0
T2	Extremely coarse textured soil	N5	B.S >75 % pH: 7.0-8.5
T2a	Pure sand, of particle structure	N6	Soil excessive calcareous >30%
T2b	Extremely coarse textured soil (> 45% coarse sand)	**Soluble Salt Content (S)**	
T2c	Soil with non-decomposed raw humus (> 30% organic matter) and fibrous structure	S1	< 0.2 %
		S2	0.2-0.4 %
T3	Dispersed clay of unstable structure (ESP > 15%)	S3	0.4- 0.6 %
		S4	06- 0.8 %
T4	Light textured soil, fS, LS, SL, cS and Si	S5	0.8- 1.0 %
T4a	Unstable structure	S6	> 1.0 %.
T4b	Stable structure	If Na_2CO_3 is present in the soil (alkali soil)	
T5	Heavy-textured soil: C or SiC	S7	Total soluble salt (including Na_2CO_3) 0.1-0.3%
T5a	Massive to large prismatic structure	S8	0.3-0.6%
T5b	Angular to crumb structure or massive but highly porous	S9	> 0.6%
		Mineral Exchange Capacity (A)	
		A0	Exchange capacity of clay < 5 $cmol.kg^{-1}$
T6	Medium-heavy soil: heavy SL, SC, CL, SiCL, Si	A1	Exchange capacity of clay < 20 $cmol.kg^{-1}$ (probably kaolinite and sesquioxides)
T6a	Massive to large prismatic structure		
T6b	Angular to crumb structure (massive but porous	A2	Exchange capacity of clay from 20 to 40 $cmol.kg^{-1}$
T7	Soil of average, balanced texture: L, SiL and SCL	A3	Exchange capacity of clay >40 $cmol.kg^{-1}$

fS: fine sand, LS: loamy sand, SL: sandy loam, S: Sand, C: Clay, Si: Silt, SiC: Silty Clay, cS: Coarse sand,

Results and Discussion

Soil and land quality or productivity is described the soil's or land's ability to perform and to sustain crop productivity and to provide a growth medium for plants (Wander and Bollero 1999; Southorn and Cattle, 2000). The digital soil map base preparation is the first step towards the presentation of a GIS module for the land productivity index. Soil map was digitized and database was prepared. A total of 14 different polygons or land mapping units (LMU) were determined in the base map and were also given soil characteristics for each LMU. According to the methodology, it should be highlighted that 14 LMUs were calculated by taking into consideration their soil characteristics ratio and coded (Table 7). The results of the processing of the parametric evaluation system for land productivity index were given in Table 8 and their maps were generated using GIS technique (Figure 2).

According to results, while most of the study area's land productivity (45.4%-800.0 ha) consist of excellent and good classes (I and II) in terms of agricultural uses, it was found that 19.7% (346.6 ha) of study area has average (III), 25.1% (441.6) of it has poor (IV) and rest of it (9.8%) has extremely poor or nil (V).

This study demonstrated that nearly half of the study area has productive lands. However, near vicinity of the Kızılırmak River formed on coarse sand and gravel sediment deposit and west part of the study area have low productive lands located on steep slope or hilly topography and low soil depth.

Table 6. Ratings of different soil and land characteristics

Factors	Crop Growing	Pasture	Tree Crop
H			
H1	5	5	5
H2a*	10	20	10
H2b	20	20	10
H2c	40	30	10
H3a	50	30	10
H3b	60	40	20
H3c	70	60	40
H4a	80	70	70
H4b	90	80	90
H4c	100	90	100
H5	100	100	100
N			
N1	40	60	80
N2	50	70	80
N3	60	80	90
N4	80	90	100
N5	100	100	100
N6	80	90	100
O	H1H2H3 D3D4	H4H5D1D2	
N1	85	70	
N2	90	80	
N3	100	90	
N4	100	100	
N5	70	70	
A			
A0	85		
A1	90		
A2	95		
A3	100		
M	H1H2H3	H4 H5	
M1	85	85	
M2a	85	90	
M2b	90	95	
M2c	95	100	
M3a	90	95	
M3b	95	100	
M3c	100	100	

Factors	Crop Growing			Pasture	Tree Crop
D	H4, H5	H2,H3			
D1	10	40		60	5
D2	40	80		100	10
D3	80	90		90	40
D4	100	100		80	100
P					
P1	5			20	5
P2	20			60	5
P3	50			80	20
P4	80			90	60
P5	100			100	80
P6	100			100	100
T					
T1a	10			30	50
T1b	30			50	80
T1c	60			90	100
	H4,5,6	H3	H1,2		
T2a	10	10	10		
T2b	30	20	10		
T2c	30	30	30	The same rating as for pasture	The same rating as for tree crops
T3	30	20	10		
T4a	40	30	30		
T4b	50	50	60		
T5a	50	60	20		
T5b	80	80	60		
T6a	80	80	60		
T6b	90	90	90		
T7	100	100	100		
S	T1,2,4	T5,6,7			
S1	100	100			
S2	70	90			
S3	50	80			
S4	25	40			
S5	15	25			
S6	5	15			
S7	60	90			
S8	15	60			
S9	5	15			

* Rating for H2a is 10; when the soil is irrigated the rating becomes 100

Table 7. Codes of LMUs and productivity index values for each LMUs

Codes of LMUs	LMUs of Soil Series	Index Value of LMUs	Codes of LMUs	LMUs of Soil Series	Index Value of LMUs
1	Kz4.Ad1a	5.60	8	Hz1.Dd3i	18.70
2	Kz3.Ad1a	17.70	9	Hz1.Ed1a	0.50
3	De1.Ad2i	30.20	10	Cy1.Ad4i	79.20
4	Gk1.Ad4i	82.50	11	Ay1.Ad4i	32.40
5	Tt1.Dd2i	4.10	12	Ay1.Ad4y	17.30
6	Ya3.Ad1a	61.30	13	Cf3.Ad3i	79.60
7	Cf2.Ad4y	53.50	14	Tt1.Cd3i	25.90

Table 8. Distribution of land productivity index of the study area

LPI	Area (ha)	Ratio (%)
Excellent	543.3	30.8
Good	256.7	14.6
Average	346.6	19.7
Poor	441.6	25.1
Extremely poor or nil	174.2	9.8
Total	1762.4	100

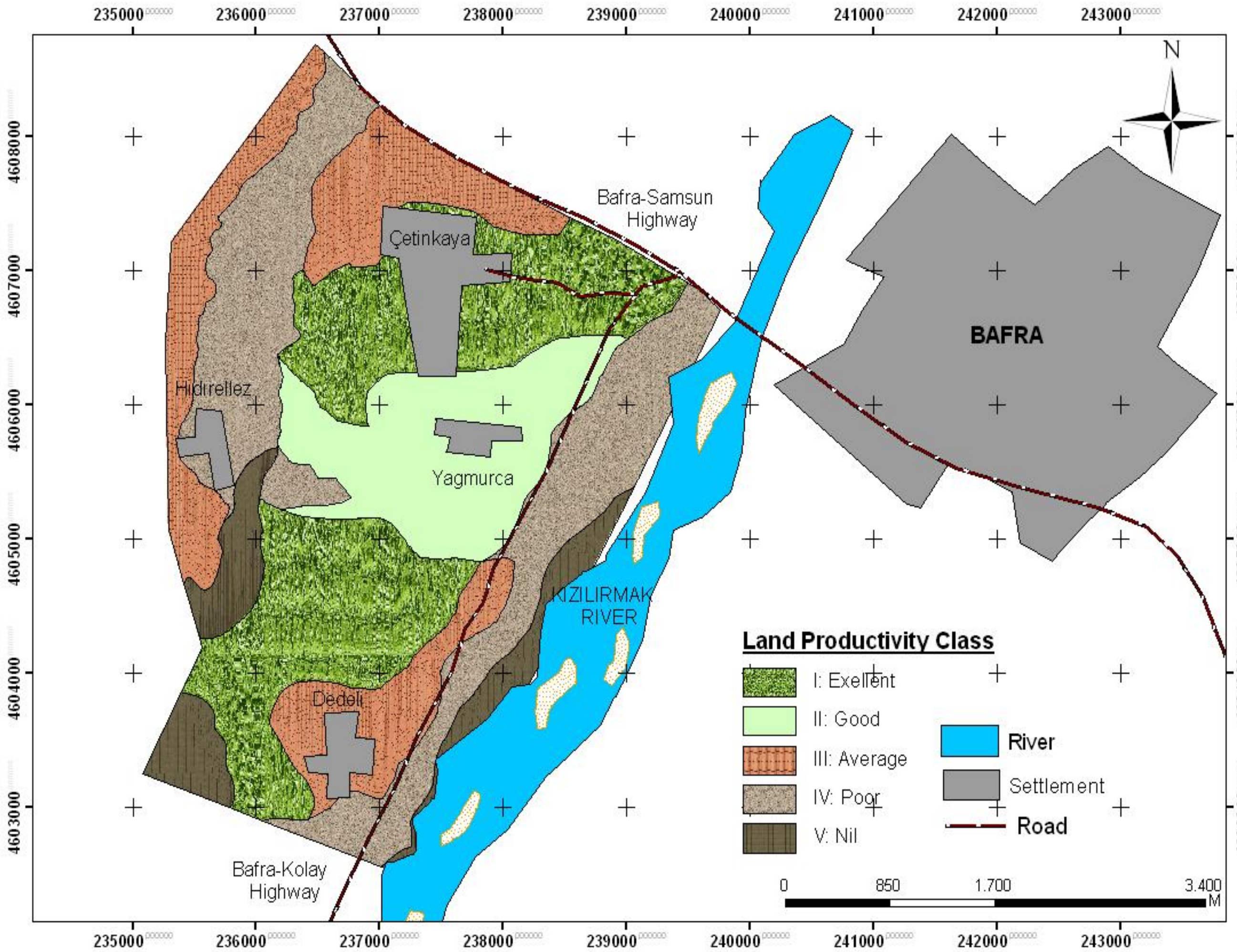

Figure 2. Land productivity map of the study area

Conclusion

Achieving and maintaining good land quality is essential for sustainable agricultural production in an economically viable and environmentally safe manner (Devi and Kumar, 2008). The concept of soil and land quality is useful for modelling agricultural systems, permitting objective comparison of production system in different locations and serving as a framework for ecological assessment

It is necessary to use the modern methods of surveying and analysis tools. That's why, GIS with its capability of data collection and analysis is now viewed as efficient and effective tools for irrigation water management. The capability of GIS to analyze the information across space and time would help in managing such dynamic systems as irrigation systems. The study shows the efficacy of this tool to analyze the information on irrigation system in various domains in an integrated manner to understand the system. It is also very easy to update data involved in GIS database with more accuracy and reliability.

Next to this study, more research should be devoted to these important topics, in particular validation of usefulness of LPI in decision making and implantation. The similar research should be also conducted for different soil types and environments.

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