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Development of land quality indices from edaphological data –a case study in shrink-swell soils of central India

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Abstract: The present study used water use efficiency (WUE) as an indicator of land quality index (LQI), through a composite Water Use Efficiency (GMWUE), on the line of FAO's land evaluation index. The GMWUE is a multiplicative function of water use efficiency (WUE) of individual crop/cropping system raised within a micro agro-edaphic environment (AEE). A relative LQI scale has been developed considering LQI for the most productive land as 100 and accordingly the LQI of other land has been fixed. The experimental cropping systems were cotton (sole), sorghum-wheat, soybean-wheat, sorghum–gram and soybean–gram for two years under normal rainfall in typical shrink-swell soils of Nagpur district of Maharashtra. The soybean-wheat system had highest water use (WU) of 586.8 to 755.9 mm followed by sorghum-wheat, soybean-gram, sorghum–gram and sole cotton. The WUE was highest for sole cotton (4.8-11.5 kg $ha^{-1}mm^{-1}$) followed by soybean-gram (3.7-10.16 kg $ha^{-1}mm^{-1}$). The LQI in terms of GMWUE was 100 for Vertic Haplustepts occurring in the lower piedmont plain whereas it was 51 for Typic Haplustepts and 48 for Typic Haplusterts representing the upper piedmont and valley plain, respectively.

Additional Key words: *water use efficiency, land quality index, catena*

Introduction

The soil quality is the capacity of a soil to perform specific kind of function within natural or managed ecosystem boundaries that sustain plant and animal productivity, while maintaining the water and air quality (Karlen *et al.* 1997). As soil is polygenetic, heterogeneous and its performance is climate specific, it often dictates the limit and range of certain soil properties which can be used as quality indicator such as soil organic carbon, pH dependent cation exchange capacity, available water content (AWC) and water use efficiency, a climate dependent parameter. As such, assessment of the land quality rather than soil quality represents the true quality index of a soil in a given set of agro-environment (Das and Dutta 2000; Mandal *et al.* 2001). Research on multifunctional LQI development based on biophysical parameters has been repoted earlier (Mandal *et al.* 2002). However, there is a need for developing an agro-edaphic parameter-based Land Quality Index (LQI) which may addresses the biophysical constraints in a single measurable parameter. As such the WUE, as a whole integrates the influence of all biophysical factors of exploitable soil volume and root interaction. Land quality assessment based on composite index of WUE of several crops within an ecosystem, will therefore, indicate the overall capability of the land to support the agriculture in a landscape. Through the present study, an attempt has been made to develop crop performance- based simplified LQI in shrink- swell soil in a representative catena of Nagpur District, Maharashtra.

Materials and Methods

The study area, a micro watershed with an area of 75 ha is located about 22 km west of Nagpur, Maharashtra, India (Fig. 1). The area is characterized by dry sub-humid ecosystem with mean annual rainfall of 1056 mm and mean

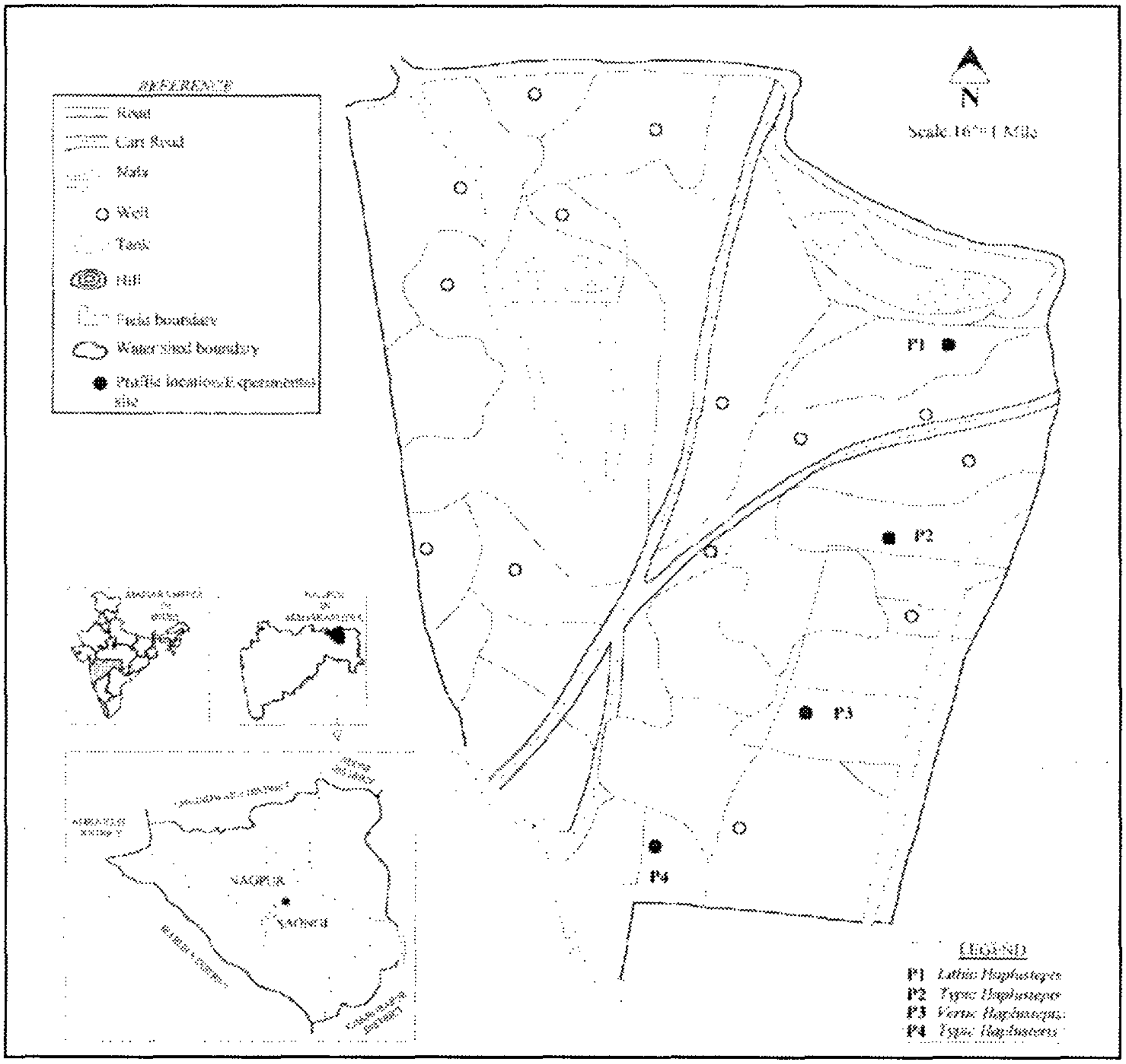

Fig. 1 : Location of the study area

growing season rainfall of 852 mm. The geomorphic analysis identified six distinct geomorphic units as hill top, escarpment, pediment, upper piedmont plain, lower piedmont plain and narrow valley.

Soil characteristics

The soils are grayish brown to dark brown in colour (10 YR) with moderate medium sub- angular blocky structure (dominant) and strong, medium to coarse angular blocky in Bss horizon. The soils of pediment surfaces are shallow Lithic Haplustepts (P1) but moderately deep (55 cm) in upper piedmont (Typic Haplustepts, P2) underlain by saprolite, depositional soils of lower piedmont (Vertic Haplustepts,P3) and valley (Typic Haplusterts, P4) are deep. The soils are clayey, calcareous and alkaline (pH > 8.0) and EC less than 1 dSm^{-1}. Available water holding capacity ranged from 10 to 17 per cent (w/w) and it increased with depth and clay content. CEC varied from 30 to 62 cmol (p^{+}) kg^{-1} and is dependent on clay content. The organic carbon is low to medium. Ca^{+2} dominates the the exchange complex followed by Mg^{+2}, K^{+} and Na^{+} and thse soils are highly base saturated.

Experimental

The on-farm experiments involving different crop sequences were carried out. The cotton hybrid (H4), hybrid sorghum (CSH-9) and soybean (PKV- 472) were grown in rainy season and gram (Chaffa) and wheat (LOK-1) in post rainy season. The crops in P1 virtually failed. The crop biometric observation and the yields were recorded. The crop ETc was computed using rainfall, crop coefficient, soil physical parameters and crop characteristics as outlined in CROPWIN (Ver. 5.7) (FAO 1997) .The root mean square of WUE (GMWUE) values of major crops/cropping system were computed as:

$$GMWUE = \frac{1}{N} \sqrt{N_1 WUE_1 \times N_2 WUE_2 \times \ldots N_n WUE_n} \quad (i = 1 \text{ to } i = n)$$

$$= \frac{1}{N} \sqrt{NiWUEi}$$

Where GMWUE is the geometric mean of water use efficiency and I, stands for mean of i^{th} crop water efficiency, N = Total no. of crops

The LQI was computed as the root mean of LQI, very similar to that of land evaluation index suggested by Khiddir (1986).The logic behind use of root mean value is to minimize the effect of year to year variation in yield and WUE.

The scale of LQI of $GMWUE_{max} = 100$ has been defined as the soils having highest GMWUE and accordingly the LQI of the other lands are calculated with reference to the scale of 0 - 100.

Results and Discussion

The monthly rainfall data (1990-1991and 1991-92) indicate that during both the years the rainfall (Fig. 2) was below normal (variation within ± 20 per cent from the mean 960 mm). Total rainfall during 1990-91 and 1991-92 were 857.2 mm and 768.7mm, respectively during the crop growing season and the rainfall distribution in 1990 was better than in 1991.

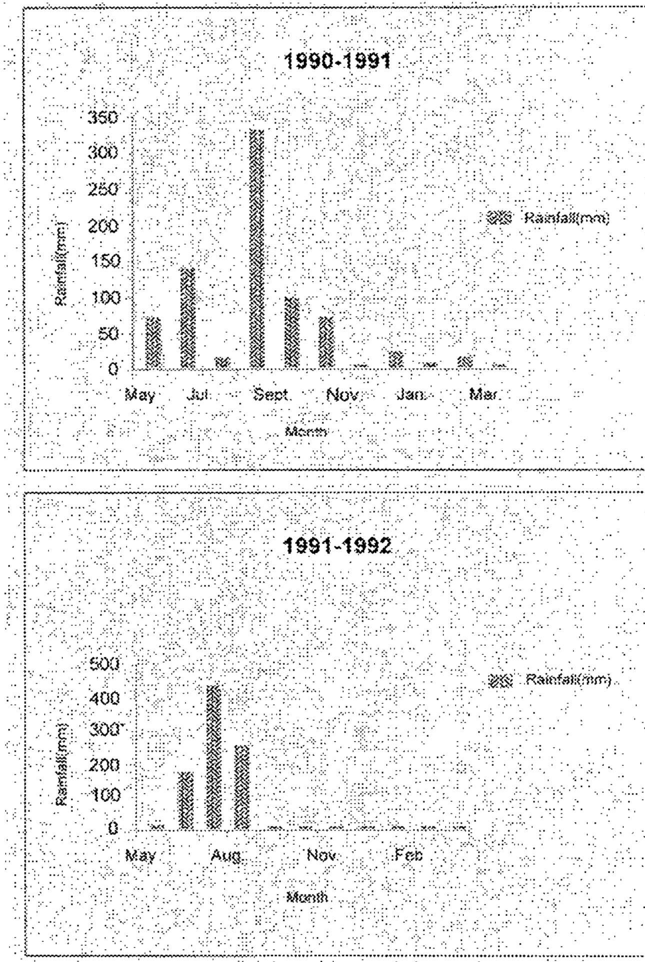

Fig. 2 : Rainfall distribution during experiment

Water use and water use efficiency

The periodic variation in crop ETc of soybean, sorghum, cotton, wheat and gram (Fig. 3) indicates that the ETc varied from 1.5 mm day^{-1} to 4.5 mm day^{-1} in 1990 and from 1.5 to 3.5 mm day^{-1} in 1991 for soybean and 1.8 to 3.8 in 1990 and 1.7 to 3.9 day^{-1} in 1991 for sorghum. Similarly the ETc for cotton for 1990-1991 varied from 0.9 mm to 4.5 mm day^{-1}.The ETc for the post rainy crop varied from 1.20 mm day^{-1} to 5.25 mm day^{-1} for wheat and 1.1 mm day^{-1} to 3.49 mm day^{-1} for gram.

WU and WUE data related to crop/cropping system and cropping sequence (Table 2) indicate that the water use for sole cotton varied from 289.6 to 360.9 mm.in different soils and years. Similarly, the water use varied from 616.3 mm to 712.5 mm for sorghum- wheat system and it was 536.3 to 755.9 mm for soybean-wheat system. The water use for

Table 1a. Characteristics of soils

Soil	Horizon	Depth (cm)	Coarse fragments (%)(>2mm)	Particle-size distribution (%) Sand (2.0 -0.05 mm)	Silt (0.05 0.002 - mm)	Clay (0.002 mm)	Bulk density (Mgm^{-3})	Air dry moisture content (w/w)	Water Retention (w/w) 33 kPa	1500 kPa
								%		
P1 (Pediment)	Ap	0-10	42.0	19.0	36.8	44.2	1.62	11.5	28.0	16.5
	Bw	10-26	43.5	30.3	36.9	32.8-	1.60	10.3	27.7	17.4
P2 (Upper Piedmont)	Ap	0-17	3.5	14.0	31.0	55.0	1.71	5.12	38.8	25.9
	Bw1	17-34	3.8	16.0	24.0	60.0	1.73	6.30	40.7	27.8
	Bw2	34-45	4.5	30.8	20.2	49.0	1.75	4.00	34.6	23.2
P3 (Lower Piedmont Plain)	Ap	0-17	2.5	14.4	24.9	60.7	1.70	5.63	38.2	26.2
	Bw1	17-33	3.5	20.0	17.8	62.2	1.70	5.75	37.6	24.8
	Bw2	33-49	6.5	23.4	13.1	63.5	1.71	6.02	40.8	26.1
	Bw3	49-100	8.8	26.3	9.9	63.8	1.73	6.72	40.6	26.2
	BC	100-120+	10.5	33.2	24.3	42.5	1.75	4.20	27.3	17.1
P4 (Valley Plain)	Ap	0-15	2.1	28.5	22.2	49.3	1.70	5.10	35.5	22.5
	Bw1	15-35	3.0	28.9	17.6	53.5	1.71	6.20	37.4	23.7
	Bw2	35-88	5.3	27.0	13.5	59.5	1.73	6.10	40.2	25.3
	Bss1	88-113	8.3	29.0	8.8	62.2	1.74	6.25	42.7	26.8
	Bss2	113-150	7.0	30.0	4.0	66.0	1.76	6.68	45.1	28.4
	BCk	150-160+	12.0	40.8	4.6	54.6	1.76	5.70	31.9	19.9

sorghum-gram and soybean-gram varied from 353.9 to 409.7 mm and 371.7 to 453.1 mm, respectively. The WUE (Table 3) indicates that sole cotton had highest WUE for all soils, ranging from 4.8 to 11.5 kg ha^{-1} mm^{-1}. The average amount of water use per day varied from 3.5 to 4.2 mm as observed for arable crops under tropical environment (Kowal and Kassam 1973; Kassam and Kowal 1975).

Yield and WUE relationship

The correlation between yield (cotton equivalent) and WUE for different soils (Fig. 5) indicated a quadratic function relationship. The high degree of correlation indicates that the WUE computed from CROPWAT model and the crop yield are in well agreement, and hence WUE can be used in LQI computation instead of yield. The significant negative correlation in P3 soil indicates that WU and yields are not related. This situtation calls for revision of the FAO- based CROPWAT programme (Mandal *et. al.*, 2005). The high yield in P3 soil is attributed to favourable Ca^{2+}/Mg^{2+} ratio, which may have helped in improving the drainage (Kadu *et al.* 2003).

LQI of cultivated soils in the catena

The highest GMWUE (36.4) for P3 soil indicates that soils have an unique quality for producing higher biomass. Kadu *et al.* (2003) highlighted the hydraulic conductivity as an unique soil quality parameter for Vertisoils, responsible for significant yield difference in cotton in a comparable agro-environment conditions. Therefore, under the situation of micro agro- environment (watershed), and the low level of agro-management, the (P3) soils may be considered having Land Quality Index of 100. Keeping this LQI as 100, the calculated LQI for other soils (Table 2) indicates that P2 and P4 soils have LQI of 51 and 48, respectively and management shrink-swell soil.

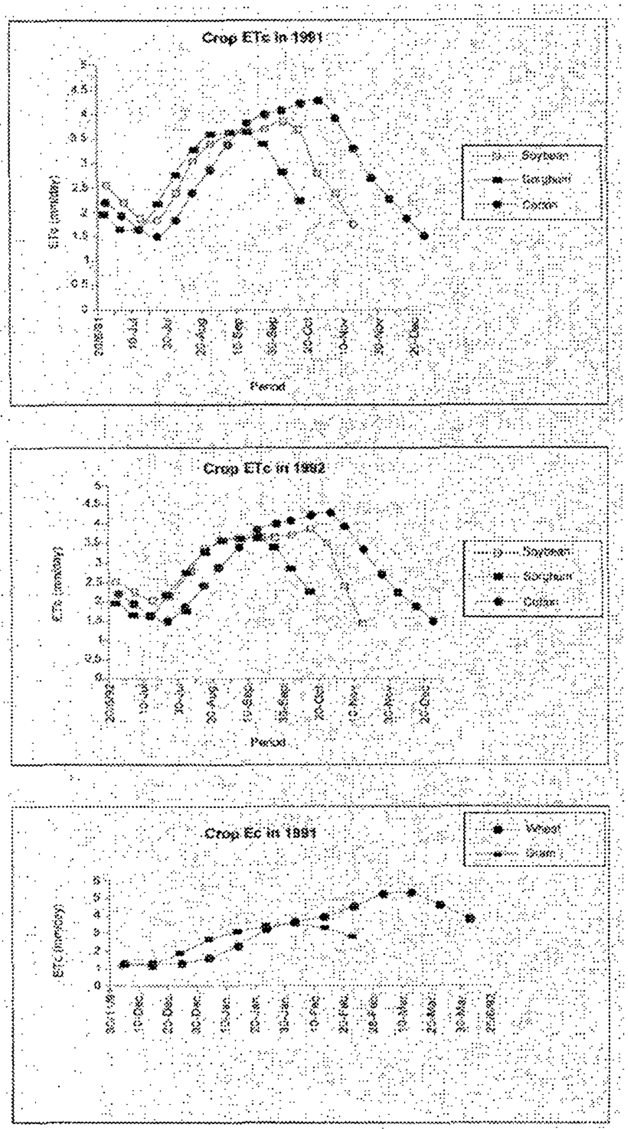

Fig. 3: Variation in crop ETc during experiment

LQI and management of shrink-swell soils

As per latest estimate, the Typic Haplusterts (low LQI soils) occupy significant area (27.9 million hectare area out of 72.9 m. ha shrink-swell soil area) in India. These Vertisols are seldom cultivated by the farmers in rainy season kept fallow for post rainy crop because of poor trafficability and proneness to waterlogging in the rainy season. This practice results in accelerated run-off and soil erosion. The question arises how to manage this vast soil with low LQI? Infact, the timing of tillage is the key to utilize these soils for successful cropping. The dry seeding techniques are often applied a few days before the commencement of rain to

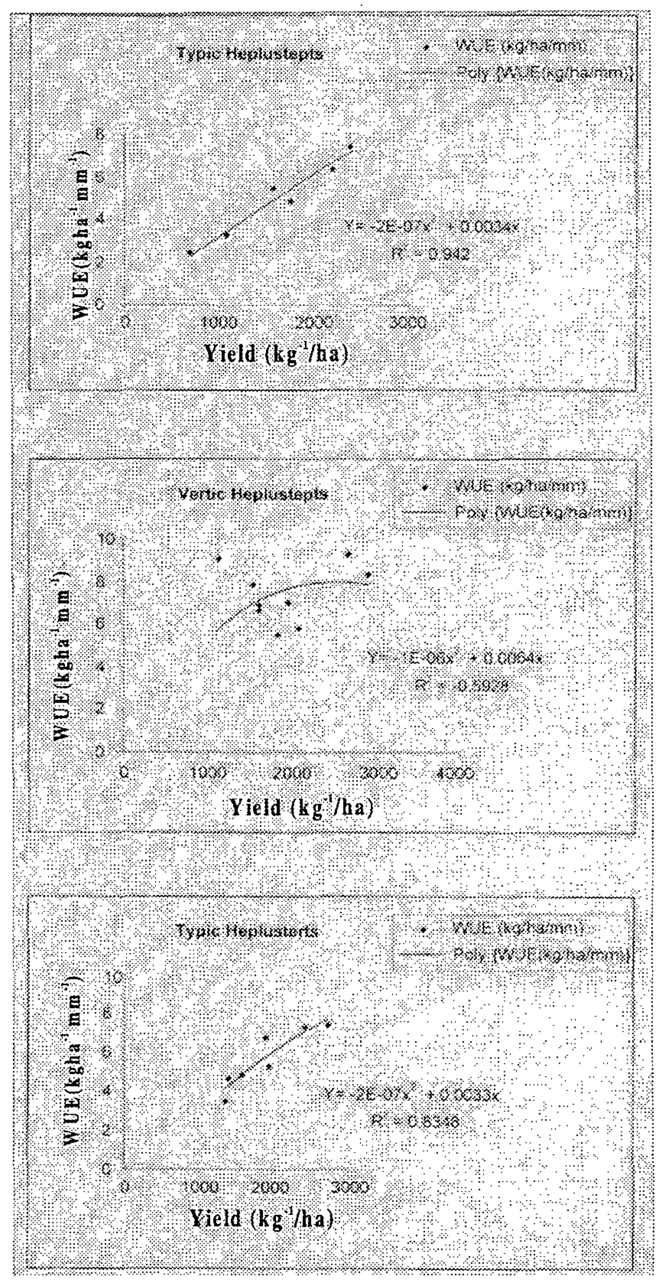

Fig. 4: WUE and yeild relation in Saongi watershed

overcome these difficulties to some extent. Dry seeding is feasible where rainfall commences at the same time each year. This technique is in fact, practised by the farmers of Akola regions of (Maharashtra state) India. Reddy and Virmani (1980) suggested that the location with moisture availability (P/PE) of 0.66 or more pose waterlogging hazard, impairing root respiration and this can be avoided by digging a small farm pond, (water harvesting pond) at the down slope of the field (to collect the excess water), which may be used

Table 1b. Chemical characteristics of soils

Soils	Hori-zon	Depth (cm)	pH (1:2.5)	E.C. (1:2.5)	Exchangeable bases Ca++	Mg++	Na+	K+	Cation exchange capacity	Base satura-tion	O.C	Calcim carbonate
					cmol(p+)kg-1					(%)		
P1	Ap	0-10	8.20	0.20	18.50	8.0	0..70	0.25	30.0	91.5	0.50	5.9
(Lithic Haplustepts)	Bw	10-26	8.2	0.21	29.07	8.05	0.38	0.21	37.0	86.8	0.28	8.2.
P2	Ap	0-17	8.26	0.20	35.00	14.00	0.75	0.45	55.5	90.5	0.54	10.00
(Typic Haplustepts)	Bw1	17-34	8.26	0.25	36.50	21.00	0.81	0.39	61.0	96.2	0.48	11.50
	Bw2	34-45	8.30	0.25	30.60	15.50	0.87	0.32	48.0	98.5	0.40	12.00
P3	Ap	0-17	8.16	0.20	30.2	20.56	0.75	0.62	59.6	87.3	0.58	6.75
(Vertic Haplustepts)	Bw1	17-33	8.17	0.20	32.58	18.58	0.78	0.62	60.0	87.6	0.49	7.00
	Bw2	33-49	8.19	0.20	33.71	18.00	0.81	0.62	61.5	87.8	0.49	7.20
	Bw3	49-100	8.27	0.25	35.00	17.00	0.81	0.68	60.5	88.4	0.47	7.50
	BCk	100-120+	8.34	0.25	24.00	16.00	0.87	0.33	45.0	91.5	0.31	12.50
P4	Ap	0-15	8.16	0.20	27.26	21.43	0.75	0.31	55.0	90.4	0.64	8.50
(Typic Haplusterts)	Bw1	15-35	8.24	0.20	29.14	20.68	0.93	0.31	56.0	91.0	0.61	9.25
	Bw2	35-88	8.39	0.20	32.50	18.26	1.25	0.37	56.0	93.5	0.52	10.00
	Bss1	88-113	8.40	0.20	35.50	18.20	1.25	0.37	58.0	95.3	0.41	10.50
	Bss2	113-150	8.74	0.22	39.40	15.20	1.25	0.37	58.5	96.1	0.40	12.75
	BCk	150-160+	8.80	0.25	32.00	17.00	1.06	0.37	52.5	96.1	0.33	16.25

Table 2 : Water Use efficiency of different cropping systems

Soils	Crop sequence	Water use (mm) 90-91	91-92	Water use efficiency ($kg\ ha^{-1}\ mm^{-1}$) Average	Geometric mean WUE	Land Quality Index (LQO)
P2	cotton (sole)	325.7	350.9	11.5		
	sorghum-wheat	616.3	698.4	6.83		
	soybean-wheat	629.5	735.9	3.07	18.4	51
	sorghum-gram	401.2	398.3	3.69		
	soybean -gram	414.4	435.8	10.16		
P3	cotton (sole)	289.6	348.4	10.79		
	sorghum-wheat	625.7	653.2	8.72	36.4	100
	soybean-wheat	586.8	730.8	6.74		
	sorghum-gram	363.2	353.9	6.38		
	soybean -gram	371.6	431.5	9.59		
P4	cotton (sole)	341.4	360.9	9.23		
	sorghum-wheat	635.5	712.5	7.55		
	soybean-wheat	6.48.9	7.55.9	5.06	17.5	48
	sorghum-gram	421.7	409.7	4.68		
	soybean -gram	435.1	453.1	6.77		

to irrigate the crop to mitigate the prolonged dry spell as well as one or two supplemental irrigation to the post rainy crops. Bhandarkar and Nimje (1996) found that the dugout ponds of 3 m depth with capacity of 2.2 ha-m storage is economically viable for 6 ha land in Vertisols of Central India, for supplemantal imigation. Therefore, the simplest method of computing area specific LQI evaluation may be helpful to form the scientific basis in assessing the land value for revenue assessment, and also for fixing insurance premium.

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