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Economic loss estimation under rainfall aberration in semi-arid tropics of India

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ABSTRACT

The paper highlights a method for computation of economic loss in high and normal rainfall year *vis-à-vis* drought year (minimum loss), based on erosion soil loss value for the state of Maharashtra under existing cropping system and market scenario. The study indicated that total economic loss in semi-arid tropics (SAT) of Maharashtra is to the tune of ₹ 15791.67 million for high rainfall year,1.81 times and 3.81 times higher than the normal and drought years, respectively. Rainfall aberration index (δc) computed from the economic loss (minimum erosion during the dry year as a denominator and the difference between economic loss from high rainfall or normal rainfall year from dry year as numerator), varied from 1.07 to 8.98 for high rainfall year. The region under soybean and cotton shows the lowest aberration index of 1.94 and 1.07, respectively whereas, the groundnut, pearl millet, sorghum and pigeon pea are relatively less friendly towards the conservation of soil resources in advent of rainfall aberrations. A linear mathematical model with economic coefficient of crops loss due to erosion has been formulated under SAT. The model may help in assessing the economic loss in aberrant rainfall years at macro scale and suggesting the prioritized conservation measures based on economic loss of production due to soil erosion.

1. INTRODUCTION

Climatic aberration, mainly due to rainfall fluctuation in regional scale (Kumar *et al.,* 1992; IPCC, 2007) is being witnessed through unprecedented cyclones, floods and heavy down pours which is expected to wash away the clay and organic matter from surface layer of soils, that contributes 50-90% of cation exchange capacity, impoverishing it from the macro and micro nutrients.

The soil loss from the black soil regions of India is in the range of 20 to > 100 t ha^{-1} yr^{-1}. The loss of productivity of sorghum, pigeonpea, groundnut and soybean is within 10%, 10-35% and 35-50% under slight, moderate and severe degree of erosion, respectively (Yadav *et al.,* 1993). Economic evaluation of land degradation has been reported for India (Singh *et al.,* 2003; Sharda *et al.,* 2010). The estimates of production loss due to soil erosion by various agencies vary widely as they are based on gross assumptions and aggregated data without considering the prevailing erosion rates in different Agro-Ecological Sub-Regions (AESRs) and the types of soils.

The crop yield loss assessment due to the climatic aberration are generally estimated through three types of models: i) Empirical models (Lobell *et al.,* 2008), ii) Mechanistic crop models like Decision Support System for agro-technology Transfer (DSSAT), iii) Erosion Productivity Impact Calculator (EPIC) (Fischer *et al.,* 2005) and iv) Niche based models like Ecocrop (Lane and Jarvis, 2007). All these models, though estimate the crop yield loss, but the works on soil degradation-based economic loss assessment are scanty. The objective of the present study encompasses the development of methodology for computing economic losses in high, normal and low rainfall year through a case study for arable land use of Maharashtra state, India.

2. MATERIALS AND METHODS

Study Area

Maharashtra state (30.76 m ha) is situated between 15°44' and 21°40' latitude and 73°15' and 80°33' longitude. The state is divided into 6 agro-ecological regions and 12 agro-ecological sub-regions (Sehgal *et al.,* 1992; Velayutham *et al.,* 1999). The forest area of the state occupies only 6.6 m ha (17.3% of TGA). The eastern fringe of the state covers 60% of the good forest area. The major forest types identified are tropical evergreen forest, tropical moist and dry deciduous, tropical thorn forest and littoral forest. The geological formation of the state includes the Deccan trap, Lameta beds, Gondwana and Vindhyan system.

It is the largest state of Peninsular India with shrink-swell soil occupying 16.8 m ha, having 7% of the degraded land of India. Out of the five soil orders, Entisols cover largest area (36.8%) followed by Inceptisols (30.9%), Vertisols (26.3%), Alfisol (5.6%) and Mollisol (0.1%). The soils of the Western Ghats and Konkan area are generally shallow, while the soils of the eastern plateau are moderately deep to deep. Major problem faced by the state are erosion induced soil degradation, impoverishing soil and land quality of Vertisols and associated soils (Mandal *et al.,* 2001), and loss of nutrients and productivity. The problem has been more severe in recent years due to rainfall fluctuation. A heavy rainfall of more than 300 mm in a single day in Akola in the month of August, 2007 and Nagpur in the month of July, 2009 (http://www.mahaagri.gov.in/rainfall/index.asp) has been observed out stripping the quantum of rainfall received in a month.

Soil Loss Estimation

The potential soil loss of entire Maharashtra (Challa *et al.,* 2001) computed by NBSS&LUP, Nagpur and CSWCRTI, Dehradun from the data of Soil Resource Mapping (SRM) Project employing Universal Soil Loss Equation (USLE), (Wischmeir and Smith, 1978) has been used for the present work. The grid information at (10 x10 km^2) scale for 2735 locations of Maharashtra was used for developing soil erosion map. The potential soil erosion map was generated from point data converting into polygon using SPAN GIS software. The soil erosive factor (R) of USLE was taken from computed value of erosivity Index (EI_{30}) from recording type rain gauge chart. Soil erosivity factor (K) was computed from soil properties as per the following formula:

$$K = 1.2917[2.1\times10^{-4} M^{1.14}(12-a) + 3.25(b-2) + 2.5(c-3)]/100$$

Where, M = (silt + clay) %; a = Per cent organic matter; b = The soil structure code used in soil classification; and c = The profile permeability code.

The slope length and steepness (topographic) factors were calculated using the formula (Wishmeir and Smith, 1978):

$$LS = (\lambda/22.13)^m (0.065 + 0.045S + 0.0065S^2) \quad \text{...(1)}$$

Where, λ = slope length (m), s = slope gradient (%) and m = an exponent with different values (m = 0.2, if slope < 1%; m = 0.3, if slope < 3 and >1%; m = 0.4, if slope < 5 and >3%; m = 0.5, if slope $\geq$ 5%.

The crop management factor has been taken as 1.0 in absence of specific crop management data (Challa *et al.,* 2001). The district-wise soil erosion classes in Maharashtra reported by Challa *et al.* (2001) were considered for computation. The soil loss was estimated using USLE for Maharashtra (Challa *et al.,* 2001) and was categorized as very slight (< 5 t ha^{-1}yr^{-1}), slight (5-10 t ha^{-1}yr^{-1}), moderate (10-15 t ha^{-1}yr^{-1}), moderately severe (15-20 t ha^{-1}yr^{-1}), severe (20-40 t ha^{-1}yr^{-1}), very severe (40-80 t ha^{-1}yr^{-1}) and extremely severe (> 80 t ha^{-1}yr^{-1}). The erosion classes data indicated that most parts of the eastern Maharashtra are characterized by very slight to moderate category of erosion. The central and western Maharashtra although receive less rainfall but due to slope factor, majority of area falls under moderate to moderately severe erosion classes. The pockets of Western Ghats including Ratnagiri, Sindhdurg and parts of Thane and Nasik, Sangli and Kolhapur suffers from severe to extremely severe erosion because of vast upland area with red soils (Mandal *et al.,* 2010). As a whole, 67% of TGA of the state is under slight erosion, 15% is under moderate erosion and above 15% under severe class of erosion.

Economic Loss Estimation

In the present study, the methodology has been adopted based on the re-grouping of erosion classes under different rainfall conditions taking district-wise crop area and soil erosion values. The assumption of different quantum of erosion in drought, normal and high rainfall year is given in flow chart (Fig. 1).

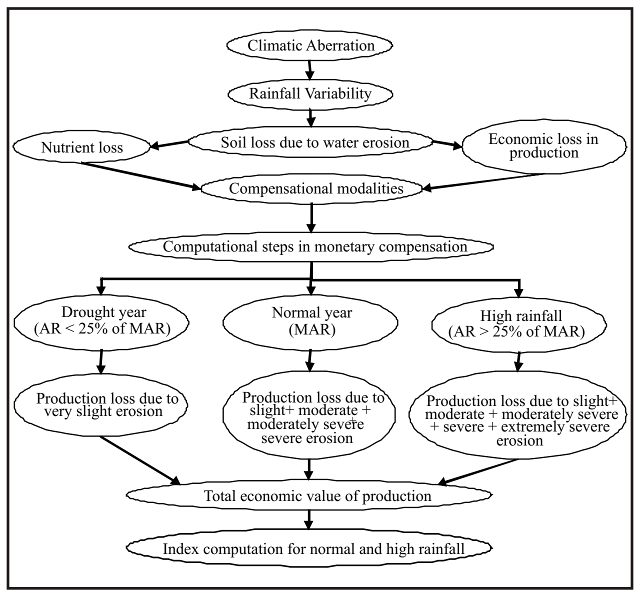

Fig. 1. Flow chart of computation and economic loss model in climatic aberration

The land use statistics of the major crops of the districts have been taken from Agricultural Statistical Information, Maharashtra state Part-II (Commissionerate of Agriculture, Govt. of Maharashtra) for the year 2006 (two years' average area has been taken) and the economic loss (EL_n) is calculated following the methodology outlined by Singh *et al.* (2003).

$$EL_n = \Sigma_{i=1}^{i=n} X_{dlk} [\Sigma Y_{ik} P_{ik} / N_{ak}] \quad \text{...(2)}$$

Where, Y_{ik} = The quantity of output of ith crop in the kth district.; P_{ik} = The farm harvest price of ith crop in the kth district; N_{ak} = Net sown area in kth district; and X_{dlk} = Area under dth category of degraded land and ith group of losses in the kth district.

In terms of economics, production loss has been assumed to be 4-6% for slight erosion class, 12% for moderate class and 14% for moderately severe class and 25 to 50% (average value of 37%) for severe class (Singh *et al.,* 2003). The sensitivity analysis was done for each crop assuming their area distributed equally among all erosion classes as no individual field record of distribution of the crop area among the soil erosion classes was available. The major crops of the districts with their area and average productivity were tabulated. For productivity, the average crop yield data of the district was considered to represent the actual farming situation practiced by the majority of the farmers with average input and without practicing soil conservation measures.

Climatic aberration index (δc) was computed from the economic loss dueto erosion taking minimum erosion in the dry year as denominator and the difference between economic loss from high rainfall or normal rainfall year from dry year as numerator, *i.e.*

$$\delta_{c\,normal} = (ELX_2\ \ ELX_1)/ ELX_1 \quad ...(3)$$

$$\delta_{c\,high} = (ELX_3\ \ ELX_1)/ ELX_1 \quad ...(4)$$

Where, ELX_1= Economic loss in the dry year; ELX_2 = Economic loss in the normal year; and ELX_3 =Economic loss in the high rainfall year.

3. RESULTS AND DISCUSSION

Economic Loss Assessment

The revenue fetched per ha of the cropland has been computed (Table 1) from the farm harvest price of the crop published by the Department of Agriculture and Co-operation, Ministry of Agriculture, Govt. of India. The data indicate that the revenue ha^{-1} of land is the highest for soybean followed by pigeon pea and groundnut in present level of technology.

Table: 1
Revenue (INR) of the major crops of Maharashtra.

Crop	Revenue in ₹ ha^{-1}(as per average yield)
Sorghum	8,065
Pearl millet	4,723
Cotton	4,750
Groundnut	15,244
Pigeon Pea	17,510
Soybean	27,940

The production loss in terms of ₹ ha^{-1} for different crops, assuming the production loss to be 5, 12, 14 and 37% in slight, moderate, moderately severe and severe classes, respectively (Singh *et al.,* 2003; Vasisht *et al*., 2003). The data indicated that ha^{-1} economic loss against sorghum and pearl millet ranged from ₹ 236 to ₹ 2984 for moderate to severe soil loss, for pulse crop (pigeon pea) (₹ 876 to ₹ 6479, oilseeds crops (groundnut and soybean) from ₹ 762 to 10038 and for cash crop like cotton, ₹ 238 to ₹1758 (Table 2). The oilseed farmers experience more economic loss in case of climatic aberration than the cereal farmers due to high market value; however, moisture availability is more for oil seed crops due to more root anchorage soil volume. Therefore, the suitable soil conservation measure is more appropriate for these crops. BB for raised bed system of cultivation developed by ICRISAT for shallow and poorly drained soils of SAT can compensate the loss due to soil erosion.

Total Economic Loss and Climatic Aberration Index

A reference computational result for different crops for high rainfall year is presented in Table 3 and a consolidated table for the total economic loss due to soil erosion for the Maharashtra is shown in Table 4.The data indicated that the total economic loss is ₹15791.67 million (Table 3) for high rainfall year. This revenue is 1.81 times higher than the economic loss in the normal year and 3.81 times higher than that of minimum production loss, which might occur even in the dry year. Among the crops, the contribution towards the economic loss is highest for soybean (47 to 51.5%), followed by pigeon pea (17.56 to18.39%), sorghum, cotton, pearl millet and groundnut (2.2 to 8.34%) in different rainfall years indicating their inverse degrees of economic loss in the year of climatic aberration. Comparing the dry year as reference year, the highest economic loss was observed for groundnut followed by pearl millet indicating their relatively less friendliness towards the conservation of soils in the advent of climatic aberration.

Government generally pays compensation to the farmer for sustainable production in climatic aberration. However, the method of awarding compensation is not based on the quantum of soil loss. The loss coefficient for each crop has been developed and presented in Table 3 (column E&F). The loss coefficient means the rate of monetary loss for per rupee production loss, which in

Table: 2
Economic loss for major crops under different degrees of erosion. **(₹ ha^{-1})**

Crops	Degree of erosion			
	Slight (5%) loss in production	Moderate (12%) loss in production	Moderately severe (14%) loss in production	Severe (37%) loss in production
Sorghum	403	968	1,129	2,984
Pearl millet	236	567	661	1,748
Pigeon Pea	876	2,101	2,451	6,479
Cotton	238	570	665	1,758
Groundnut	762	1,829	2,134	5,640
Soybean	1,397	3,353	3,912	10,338

Table: 3
District-wise economic loss due to the soil erosion in high rainfall year. **(₹ in million)**

S. No.	District	Crop					
		Pearl millet (A)	Cotton (B)	Groundnut (C)	Sorghum (D)	Soybean (E)	Pigeon pea (F)
1	Ahmednagar	235.15	16.42			215.58	450.76
2	Akola		153.86		80.26	170.12	105.89
3	Amravati		192.99		113.38	707.22	233.85
4	Aurangabad	87.14	142.38	18.54	12.23	22.79	93.75
5	Bhandara and Gondia					38.59	
6	Beed	138.97	19.35		75.26	130.13	126.20
7	Buldhana		113.26		98.64	473.44	123.82
8	Chandrapur		30.90		26.50	599.50	55.75
9	Dhule	158.82		126.53	64.85	34.52	118.53
10	Gadchiroli				12.14	12.18	4.76
11	Jalgaon	35.40		9.55	136.66	30.37	55.70
12	Jalna	41.56	99.18	2.19	14.23	53.31	95.27
13	Kolhapur			10.70	15.10	488.47	
14	Latur	4.62	4.39	25.38	148.90	564.15	156.33
15	Nagpur		49.60	12.05	45.30	909.82	123.06
16	Nanded		132.92		160.01	369.84	106.13
17	Nasik	369.49	16.62	135.40	13.01	140.73	39.56
18	Osmanabad	13.58	4.05	17.80	93.95	113.78	212.18
19	Parbhani and Hingoli	6.45	154.61		157.26	600.46	179.05
20	Pune	128.82		167.95	6.03	7.83	15.34
21	Raigarh						6.40
22	Ratnagiri						2.87
23	Sangali	100.87		109.28	203.19	82.37	
24	Satara	115.58		284.59	135.71	194.24	27.43
25	Sindhudurg			6.64			
26	Solapur	22.75	0.87	14.84	0.59		3.15
27	Thane			0.79			12.07
28	Wardha		68.35		29.31	787.53	128.21
29	Yavatmal	2.35	218.18		128.13	679.86	296.39
	Total Loss (₹)	1461.53	1417.94	942.22	1770.66	7426.85	2772.47
	Total (A+B+C+D+E+F) = ₹ 15791.67						

Table: 4
Crop-wise economic loss estimation and aberration index coefficient due to erosion in different rainfall scenarios. **(₹ in million)**

Crop	Economic loss (EL)			Climatic aberration index for normal year	Climatic aberration index for high rainfall year
	Drought year as base year (ELX1)	Normal year (ELX2)	High rainfall year (ELX3)	Qn= [(ELX2-ELX1)/ELX1)]	Qh= [(ELX3-ELX1)/ELX1]
Pearl millet	188.12 (4.54)*	1072.77 (12.27)	1461.53 (9.26)	4.70 (0.32)	6.77 (0.28)
Cotton	482.12 (11.64)	684.43 (7.83)	1417.94 (8.98)	0.42 (0.03)	1.94 (0.08)
Groundnut	94.44 (2.28)	729.42 (8.34)	942.22 (5.97)	6.72 (0.46)	8.98 (0.37)
Sorghum	482.79 (11.65)	982.30 (11.23)	1770.66 (11.21)	1.03 (0.07)	2.67 (0.11)
Soybean	2135.47 (51.54)	3671.20 (41.97)	7426.85 (47.03)	0.72 (0.05)	1.07 (0.05)
Pigeon pea	760.40 (18.35)	1608.17 (18.39)	2772.47 (17.56)	1.11 (0.08)	2.65 (0.11)
Total	4143.34 (100*)	8746.29 (100)	15791.67 (100)	14.7	24.08

*(4.54) indicates the percentage of the total loss.

present case study varied from 0.42 to 8.98 depending on the crop and base year's price situation (dry year). The higher coefficient value for pearl millet and groundnut is justified by the fact that these crops are raised in shallow to relatively deep soils. The impact of the climatic aberration is more for shallow soils, which needs more protection and conservation measures for crop cultivation and need to be adequately compensated. A generalized equation has been developed considering the percentage contribution to the total loss. The proposed Economic Loss Computation due to the soil loss for normal (CSL_n) year and high rainfall year CSL_h for major six crops of Maharashtra are:

$$CSL_n = 0.32\,YnJ_1i + 0.03YnJ_2 + 0.46\,YnJ_3 + 0.07YnJ_4 + 0.05\,YnJ_5 + 0.08YnJ_6 \quad \ldots (5)$$

$$CSL_h = 0.28YhJ_1i + 0.08YhJ_2 + 0.37YhJ_3 + 0.011YhJ_4 + 0.05YhJ_5 + 0.11Yhj_6 \quad \ldots (6)$$

Where, Yn and Yh indicate the average crop yield in normal and high rainfall year respectively. J_1, J_2, J_3, J_4, J_5 and J_6 are pearl millet, cotton, groundnut, sorghum, soybean and pigeon pea, respectively.

These models can be generalized as model for j^{th} crop for i^{th} no. of rainfall situation as under:

$$CSLij = \Sigma_{i=1}^{i=n} aij * yij \quad \dots (7)$$

Where, i = rainfall year; a = co-efficient of yield loss of j^{th} crop in i^{th} rainfall year with yield loss in monetary terms and CSL_{ij} is total monetary loss due to erosion terms of crop's market value for j^{th} crop in the i^{th} rainfall year.

4. CONCLUSIONS

The model was developed on production loss for the Maharashtra state under varied rainfall conditions, assuming existence of different categories of erosion classes. This type of economic loss estimation simplified model will help in assessing the quantum of compensation to be given to the farmers due to soil loss (natural resource degradation) and compensation amount to be distributed against each crop. The erosion loss model may also be used for carbon foot-print assessment in soils due to climatic aberrations. The economic value of nutrients due to soil erosion has not been calculated separately because under rainfed production system the land/ crop management system widely varies from plot to plot. However, when we consider the economic loss in terms of production, indirectly this issue has been addressed too. The model may be further fine-tuned considering the actual soil loss measurement for a small watershed where the major crops can be grown under different rainfall situations. Fine tuning the economic loss model of the watershed level may be scaled to the large contiguous areas for logical assessment.

REFERENCES

Challa, O., Kurothe, R.S. and Gajbhiye, K.S. 2001. Soil Erosion in Maharashtra. NBSS Pub. No. 82, NBSS&LUP, Nagpur, 51 p.

Fischer, G., Shah, M., Tubiello, F.N. and Van Velhuizen, H. 2005. Socio-Economic and climate change exchange impacts on agriculture: an integrated assessment, 1990-2080. *Phil. Trans. Royal Soc.,* 1463: 2067-2083.

http://www.mahaagri.gov.in/rainfall/index.asp viewed on 9th January, 2010.

IPCC, 2007. IPCC Fourth Assessment Report: Climate Change, IPCC, Geneva.

Kumar Rupa, Paul, K., Parthasarathy, G.B.B. and Sontakke, N.A. 1992. Spatial and Sub seasonal patterns of the long term trends of Indian Summer Monsoon Rainfall. *Int. J. Clim.*, 12: 257-68.

Lane, A. and Jarvis A, 2007. Changes in climate with modify the geography of crop suitability: agricultural biodiversity can help with adaptation. *J. Semi-arid Trop. Agri. Res.,* 4: 1-12.

Lobell, D.B., Burke M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. and Naylor, R.L. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Sci.,* 319: 607-610.

Mandal, D.K., Mandal, C., Raja, P. and Goswami, S.N. 2010. Identification of suitable area for aerobic rice cultivation in humid tropics of eastern India. *Curr. Sci.,* 99: 227-231.

Mandal. D.K., Mandal, C. And Velayutham, M. 2001. Development of land quality index for sorghum in Indian semi-Arid Tropics (SAT). *Agric. Syst.*, 70: 335-350.

Sehgal, J.L., Mandal, D.K., Mandal, C. and Vadivelu, S. 1992. Agroecological regions in India, NBSSLUP Publication 24, NBSSLUP, Nagpur, 130 p.

Sharda, V.N., Dogra, P. and Prakash, C. 2010. Assessment of production losses due to water erosion in rainfed areas of India. *J. Soil Cons.*, 65: 79-91.

Singh, R.P., Vasist, A.K. and Mathur, V.C. 2003. Quantitative assessment of economic losses of degraded land in India. Advance publishing Concept, New Delhi, 51 p.

Vasisht A.K., Singh, R.P. and Mathur, V.C. 2003. Economic implications of land degradation on sustainability and food security in India. Agropedology. 13: 19-27

Velayutham, M., Mandal, D.K., Mandal, C. and Sehgal, J.L. 1999. Agro ecological sub regions of India for Development and Planning. NBSS Publ. 35, NBSS&LUP, Nagpur, India, 452 p.

Wischmeir, W.H. and Smith, D.D. 1978. Predicting rainfall erosion loss A guide for conservation planning, Agr. Handbook No. 527, USDA, Washington, D.C.

Yadav, S.C., Sehgal, J. and Vedivelu, S. 1993. UNDP terminal technical report on study of factors of land evaluation system, NetBIOS Session Service Publication. pp. 73-100.