SOIL EROSION AND CROP PRODUCTIVITY MODEL FOR RATNAGIRI DISTRICT

A Thesis submitted to the

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In the partial fulfillment of the requirements for the degree

of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

In

SOIL AND WATER CONSERVATION ENGINEERING

By

Miss. Salunkhe Sanjani Sunil

(ENDPM 2015/098)

DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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VII. APPENDICES

APPENDIX I

Basic data used for regression analysis between erosivity index and daily precipitation

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
12/06/1988	14	35.27133		25/07/1988	30	95.81035
13/06/1988	53	195.2669		26/07/1988	32.5	25.91086
14/06/1988	68.4	282.114		27/07/1988	72	164.6733
16/06/1988	18.6	16.06147		28/07/1988	10	14.8569
17/06/1988	73.4	231.1484		29/07/1988	18.6	5.366896
20/06/1988	35	154.3204		30/07/1988	85.7	294.444
21/06/1988	20	47.30284		31/07/1988	46.4	110.7025
22/06/1988	63.8	352.9191		01/08/1988	44.4	158.2533
23/06/1988	48.6	159.234		02/08/1988	81.8	542.2852
24/06/1988	19.2	22.39763		03/08/1988	20	30.19036
25/06/1988	40	94.68777		04/08/1988	10	22.76821
26/06/1988	10	10.28634		05/08/1988	9.4	4.675491
27/06/1988	10	45.21506		06/08/1988	9.4	45.33114
28/06/1988	18.6	21.11971		07/08/1988	10.4	28.53419
29/06/1988	35.6	95.61175		08/08/1988	4.7	10.17174
30/06/1988	14.4	23.04189		09/08/1988	15	18.50776
01/07/1988	34.4	222.4367		10/08/1988	10	7.49017
02/07/1988	10	14.28971		11/08/1988	25.3	26.31758
05/07/1988	80	598.0879		12/08/1988	11.5	13.30542
06/07/1988	5	16.7865		15/08/1988	53.9	308.4406
07/07/1988	34.7	47.26682		16/08/1988	3.2	18.58624
08/07/1988	72.2	232.0753		17/08/1988	20.5	5.737464
10/07/1988	6.4	6.133595		18/08/1988	47.5	45.82173
11/07/1988	14.5	16.85568		19/08/1988	31.5	268.1094
12/07/1988	77.7	489.8101		20/08/1988	20	23.67293
13/07/1988	98.3	629.014		21/08/1988	34.8	120.2658
14/07/1988	107.2	557.6865		22/08/1988	25.8	22.89971
15/07/1988	10	22.06997		23/08/1988	29.4	58.66275
16/07/1988	44.5	26.20546		24/08/1988	10	5.314877
17/07/1988	64.7	154.0886		25/08/1988	10	21.11971
18/07/1988	120	386.3874		29/08/1988	19.9	53.8507
19/07/1988	20	21.25526		30/08/1988	10.7	18.27289
21/07/1988	14.8	2.57875		02/09/1988	51.2	712.9321
22/07/1988	46.1	95.19249		07/09/1988	22.3	27.73112
23/07/1988	20	23.29108		08/09/1988	19.5	15.78313
24/07/1988	55.8	117.1711		09/09/1988	10	60.82651

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
11/09/1988	17.6	51.1574		11/08/1989	10	7017183
13/09/1988	14.3	47.7492		12/08/1989	58.3	43.3238
15/09/1988	81	1072.42		13/08/1989	27.6	28.5413
16/09/1988	75.6	458.06		15/08/1989	10	7.17183
19/09/1988	38.4	63.0369		16/08/1989	10	14.089
20/09/1988	9.4	10.7096		17/08/1989	63.6	367.555
21/09/1988	9.5	6.55597		19/08/1989	13.6	941.693
22/09/1988	59.2	193.434		20/08/1989	25.6	35.2718
23/09/1988	28	116.357		21/08/1989	15.3	17.2435
24/09/1988	16.6	46.5393		23/08/1989	19.3	8.5898
26/09/1988	42.5	149.149		25/08/1989	8.9	8.45038
27/09/1988	91.4	554.037		27/08/1989	15.5	18.5154
02/10/1988	10	57.4865		28/08/1989	38.5	175.432
17/10/1988	11	714.525		29/08/1989	7.4	5.03919
18/10/1988	2.2	1.58272		01/09/1989	5.5	22.4742
23/10/1988	13.3	28.433		06/09/1989	6.5	1.58272
24/10/1988	14	31.6451		08/09/1989	16.2	27.1983
03/06/1989	29.4	152.668		18/09/1989	19.9	138.77
09/06/1989	41.5	106.184		20/09/1989	36.7	188.006
10/06/1989	32.3	116.709		21/09/1989	14.5	79.2787
11/06/1989	10	12.658		27/09/1989	31	107.307
12/06/1989	9.8	2.57875		01/10/1989	10	18.8899
13/06/1989	29.3	41.585		02/10/1989	10	51.772
14/06/1989	64.6	223.063		06/10/1989	10.7	57.4865
15/06/1989	30	180.408		01/06/1990	9.7	37.0308
16/06/1989	9.7	7.41943		02/06/1990	8	6.33087
17/06/1989	117.9	1229.45		04/06/1990	40.4	308.956
18/06/1989	10.6	20.4936		07/06/1990	7	2.35875
19/06/1989	5.4	1.76126		11/06/1990	76	491.089
20/06/1989	35	164.96		12/06/1990	9.5	32.7174
21/06/1989	25.2	48.5304		15/06/1990	53.4	223.859
24/06/1989	3.7	2.14921		16/06/1990	35.6	52.3747
25/06/1989	25.5	183.72		17/06/1990	132.5	1468.01
26/06/1989	0	162.677		18/06/1990	18.3	13.3294
27/06/1989	66.7	340.487		19/06/1990	16.7	4.12184
28/06/1989	69.2	176.544		22/06/1990	18.5	28.8683
29/06/1989	72	364.644		23/06/1990	14.3	28.5928
30/06/1989	78.4	10.9208		24/06/1990	64.2	296.876
08/08/1989	20	135.62		26/06/1990	161.5	1460.01
09/08/1989	3.2	11.7469		27/06/1990	58.4	60.3246

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
28/06/1990	145.7	1501.903		18/08/1990	10	9.669018
29/06/1990	58.6	262.5014		19/08/1990	35.9	114.8553
30/06/1990	31.4	38.69393		20/08/1990	12.9	2.80928
01/07/1990	16.5	7.972204		21/08/1990	18.3	5.187066
02/07/1990	10	19.81967		22/08/1990	84.3	266.8854
03/07/1990	15.4	4.416705		23/08/1990	32.5	52.5305
04/07/1990	11	2.80928		25/08/1990	19.4	13.63751
07/07/1990	15.8	43.6586		26/08/1990	17	14.33779
08/07/1990	35.3	50.22758		27/08/1990	20	11.08955
09/07/1990	10	34.69236		28/08/1990	8.8	4.601397
11/07/1990	51	167.9736		29/08/1990	20	30.78414
12/07/1990	21.1	46.51598		30/08/1990	14.9	17.33664
13/07/1990	69.9	229.6799		01/09/1990	10	7.168553
14/07/1990	23.8	55.03875		02/09/1990	18	26.65907
16/07/1990	39.2	73.38674		04/09/1990	10	14.56474
17/07/1990	43	118.9083		05/09/1990	47	136.29
18/07/1990	10	7.972204		06/09/1990	10	15.43585
19/07/1990	10	11.79553		07/09/1990	17.1	2.616426
20/07/1990	117	549.6233		11/09/1990	12.1	2.149207
21/07/1990	64	302.5994		12/09/1990	4	2.57875
22/07/1990	29.6	18.84315		13/09/1990	3.1	4.121839
23/07/1990	57.5	248.1565		20/09/1990	11	6.604314
24/07/1990	20	28.0716		23/09/1990	10	30.35182
25/07/1990	10	13.72818		24/09/1990	20	65.09503
27/07/1990	8.5	3.837825		26/09/1990	2	1.582718
30/07/1990	23.7	7.364756		02/10/1990	4.5	5.366896
01/08/1990	6	3.050397		08/10/1990	74	606.0856
02/08/1990	11.5	2.80928		09/10/1990	35.6	148.776
03/08/1990	22.4	27.08436		10/10/1990	76	150.1743
04/08/1990	31.8	10.5684		12/10/1990	9.6	16.06097
05/08/1990	19.8	40.8928		19/10/1990	20	70.10282
07/08/1990	27.4	26.20025		27/10/1990	17.9	26.5602
09/08/1990	18.6	2.872856		05/06/1991	4.3	7.41751
10/08/1990	69.3	251.0682		06/06/1991	29	225.3601
11/08/1990	113.4	307.7032		07/06/1991	400	10153.75
12/08/1990	102	296.7514		08/06/1991	235.5	3454.781
13/08/1990	35.5	18.46345		09/06/1991	176.5	2616.93
14/08/1990	24.2	7.71505		19/06/1991	23.8	91.25498
15/08/1990	150	581.1066		21/06/1991	23.7	82.88207
16/08/1990	236.3	1071.045		24/06/1991	22.5	65.98636
17/08/1990	10	5.705641		28/06/1991	105	842.175

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
29/06/1991	48.3	139.2792		14/08/1991	10	14.81844
02/07/1991	19	48.7609		15/08/1991	28	37.02639
03/07/1991	20	34.50147		16/08/1991	10	14.96066
04/07/1991	34.5	23.33933		17/08/1991	21	10.65284
05/07/1991	34.5	33.95697		18/08/1991	26	24.97942
06/07/1991	9.5	3.302157		19/08/1991	10	6.731896
07/07/1991	10	46.37318		20/08/1991	18.5	3.302157
08/07/1991	59	629.656		21/08/1991	11.8	2.57875
09/07/1991	12.2	51.77197		22/08/1991	27.8	12.69271
11/07/1991	20	70.31511		23/08/1991	10	4.416705
12/07/1991	49	281.811		24/08/1991	10	7.71505
13/07/1991	102.5	751.1784		25/08/1991	20.6	21.46758
14/07/1991	61.5	168.909		27/08/1991	10	21.32572
15/07/1991	108	237.2677		28/08/1991	10	2.374077
16/07/1991	101	442.4556		29/08/1991	9.5	12.20159
17/07/1991	59	227.1779		03/09/1991	6	1.582718
18/07/1991	60	164.1632		09/09/1991	4.8	3.837825
19/07/1991	17.5	6.6016		16/09/1991	4.2	7.045048
20/07/1991	21	32.34886		22/09/1991	20	136.9778
21/07/1991	20.6	19.96296		23/09/1991	14.5	39.25384
22/07/1991	41	55.81581		11/06/1992	40	342.1677
23/07/1991	13.8	3.837825		16/06/1992	13.1	37.92768
24/07/1991	9.8	3.837825		19/06/1992	51.3	186.4632
25/07/1991	21.8	16.71566		20/06/1992	30	208.7292
26/07/1991	10	5.366896		21/06/1992	29.5	82.36294
27/07/1991	100.2	302.3356		22/06/1992	10	22.29269
28/07/1991	100	414.2626		23/06/1992	10	6.055466
29/07/1991	50.6	120.5173		25/06/1992	4.9	1.58718
30/07/1991	79.6	302.4835		26/06/1992	10	10.33727
31/07/1991	16.5	5.875569		27/06/1992	15.6	11.629
01/08/1991	15.8	17.24346		28/06/1992	3	1.582718
02/08/1991	11.2	14.48149		29/06/1992	66.3	450.8223
04/08/1991	9.2	13.24648		09/07/1992	10	4.3323
05/08/1991	10	46.51598		10/07/1992	49.5	460.8467
06/08/1991	37.5	60.62193		11/07/1992	6.7	2.80928
07/08/1991	22.5	30.64031		12/07/1992	18.8	32.62152
08/08/1991	22.5	46.31432		14/07/1992	81.4	490.6107
10/08/1991	12.5	2.038708		16/07/1992	78.5	465.3767
11/08/1991	28.2	30.25286		17/07/1992	122.7	388.4932
12/08/1991	16.8	10.49771		18/07/1992	114.3	532.5242
13/08/1991	32.4	59.0485		19/07/1992	64	115.374

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
20/07/1992	41	60.43829		30/09/1992	16.4	18.71293
21/07/1992	40	60.4662		03/10/1992	9	14.45495
23/07/1992	32	25.19571		10/10/1992	9.3	3.61025
24/07/1992	35	25.19809		11/10/1992	10	10.5519
26/07/1992	10	3.302157		18/10/1992	10	1.929001
27/07/1992	5.9	3.050397		09/06/1993	4.2	82.50622
28/07/1992	9.5	2.57875		11/06/1993	16.5	8.609237
29/07/1992	27	60.91571		12/06/1993	12.5	27.86516
30/07/1992	12.6	5.49118		14/06/1993	20	24.18517
31/07/1992	6.5	3.050397		15/06/1993	29.5	364.753
02/08/1992	10	7.4129		17/06/1993	54	72.14074
03/08/1992	35.5	74.0985		18/06/1993	186	2836.7
04/08/1992	70.3	533.8348		26/06/1993	17	14.48179
05/08/1992	18.5	45.04788		02/07/1993	71	102.467
06/08/1992	3.4	3.837825		03/07/1993	10	28.882
09/08/1992	42.5	136.8096		04/07/1993	84	189.7127
10/08/1992	10	25.09463		05/07/1993	32	89.07143
11/08/1992	110	293.2138		06/07/1993	5.5	7.17183
12/08/1992	56.5	232.8595		08/07/1993	36.5	34.77681
13/08/1992	106.5	871.998		09/07/1993	115.4	485.2444
14/08/1992	0	276.0118		10/07/1993	29	49.15572
15/08/1992	10	13.71828		11/07/1993	31.5	39.01924
16/08/1992	49	176.1724		12/07/1993	52.5	122.5312
17/08/1992	41	129.5899		13/07/1993	19	4.416705
18/08/1992	10	11.29591		14/07/1993	54	365.6035
19/08/1992	14.3	4.830255		15/07/1993	51	251.2852
20/08/1992	10	5.835447		16/07/1993	37	49.66643
21/08/1992	37	261.048		17/07/1993	58	91.17915
22/08/1992	6.4	5.039188		19/07/1993	31	138.28
24/08/1992	12.6	50.86738		21/07/1993	26	6.189
26/08/1992	11	10.57382		22/07/1993	25	29.3259
27/08/1992	147.6	1319.172		23/07/1993	140	673.8365
28/08/1992	30	66.95104		24/07/1993	147.5	1615.664
29/08/1992	5	2.57875		25/07/1993	368	4102.287
30/08/1992	5	4.371617		26/07/1993	118	758.9329
01/09/1992	9.5	8.704949		27/07/1993	116	437.3069
02/09/1992	10	14.28971		28/07/1993	86	390.3785
03/09/1992	10	36.26463		29/07/1993	86	577.1657
04/09/1992	34.7	4.121839		30/07/1993	86	372.416
06/09/1992	10	78.88997		01/08/1993	100	92.43562
07/09/1992	10	47.03865		02/08/1993	121.5	693.4189

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
03/08/1993	9.5	7.91359		11/10/1993	8	10.44623
04/08/1993	21	41.26		13/10/1993	36.5	127.4579
05/08/1993	19	48.12764		15/10/1993	24	241.8509
06/08/1993	8.5	14.28971		16/10/1993	17	17.11175
07/08/1993	7	7.17183		05/06/1994	24.6	55.11689
08/08/1993	8	2.57875		09/06/1994	38.5	119.7386
09/08/1993	12.5	6.380001		11/06/1994	29.2	94.51901
10/08/1993	32	51.89589		12/06/1994	85	464.9276
11/08/1993	10	11.66125		13/06/1994	31	26.52856
12/08/1993	32.5	49.98653		14/06/1994	10	9.257704
13/08/1993	28	53.7051		15/06/1994	66.2	205.3549
14/08/1993	10	5.366896		16/06/1994	22.2	39.08808
15/08/1993	20	16.62509		22/06/1994	12.5	18.10563
16/08/1993	17.5	34.0689		23/06/1994	7.7	3.0945
17/08/1993	15.5	12.9711		24/06/1994	10	7.17183
18/08/1993	15.5	13.89945		26/06/1994	10	37.03082
19/08/1993	41	225.0526		27/06/1994	10	5.705641
20/08/1993	30	128.7755		29/06/1994	21	238.2855
22/08/1993	2.5	2.57875		30/06/1994	64.2	241.1279
23/08/1993	12	9.257704		01/07/1994	10	9.708895
24/08/1993	35.5	141.9333		02/07/1994	24.2	53.1643
25/08/1993	13.5	8.977146		03/07/1994	67	150.2676
29/08/1993	8.1	30.26551		05/07/1994	16.7	16.71138
31/08/1993	10	21.32838		06/07/1994	12	28.68732
01/09/1993	30.5	43.33862		07/07/1994	10	15.43585
02/09/1993	67.5	203.4672		08/07/1994	14	2.8882
03/09/1993	37	119.651		09/07/1994	10	19.5535
04/09/1993	68	327.0043		10/07/1994	27	34.48682
05/09/1993	66.5	211.3221		11/07/1994	157	1774.897
06/09/1993	16	20.49355		12/07/1994	131.3	889.3044
08/09/1993	16	72.7489		13/07/1994	53.7	56.24439
09/09/1993	20	68.46827		14/07/1994	33.5	40.95451
11/09/1993	20	42.21367		18/07/1994	20.4	9.257704
12/09/1993	24	119.2026		19/07/1994	27	22.69268
16/09/1993	32	191.8594		20/07/1994	26.9	24.59138
17/09/1993	30.5	115.3133		21/07/1994	33.7	41.79993
21/09/1993	48	693.7189		22/07/1994	53	69.96579
24/09/1993	42.5	209.9032		23/07/1994	31.5	39.65448
26/09/1993	118	785.8391		25/07/1994	10	5.366896
27/09/1993	116	501.043		27/07/1994	10	5.835447
28/09/1993	86	376.5736		28/07/1994	10	1.289375

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
08/08/1994	4.6	7.17183		10/07/1995	60	225.9736
09/08/1994	5.2	6.055466		11/07/1995	96	1428.491
10/08/1994	12.1	2.038708		12/07/1995	92.5	1113.842
11/08/1994	27.5	42.06713		13/07/1995	50	111.2892
12/08/1994	10	13.03389		14/07/1995	58.7	127.4396
13/08/1994	26.2	57.52996		15/07/1995	59.5	1248.744
14/08/1994	10	17.24346		16/07/1995	50	69.96889
17/08/1994	10	17.07165		17/07/1995	50	121.41
18/08/1994	10	24.04302		18/07/1995	50	34.48691
20/08/1994	12	4.416705		19/07/1995	78	186.7227
21/08/1994	7	2.57875		20/07/1995	66	130.4213
22/08/1994	54	242.2129		22/07/1995	20.5	17.24346
24/08/1994	9.9	10.315		23/07/1995	26.2	84.38733
25/08/1994	11	6.860343		25/07/1995	71	281.5135
26/08/1994	10	3.837825		26/07/1995	6.3	8.252
27/08/1994	52.1	236.2008		28/07/1995	24	18.27289
28/08/1994	20	2.990201		29/07/1995	108	886.6417
30/08/1994	60.1	139.5248		30/07/1995	30	49.743
31/08/1994	63	11.51348		31/07/1995	84.5	239.7938
01/09/1994	74.6	267.5998		01/08/1995	10	16.63058
02/09/1994	58.5	184.6596		02/08/1995	106.5	835.3852
03/09/1994	10	12.65834		03/08/1995	20.5	9.257704
04/09/1994	10	3.837825		07/08/1995	21	13.55438
05/09/1994	10	10.315		08/08/1995	10	9.191756
09/09/1994	65.5	181.2499		09/08/1995	12.7	34.69236
10/09/1994	26.2	159.4385		11/08/1995	13.2	10.61436
15/09/1994	39	242.6426		13/08/1995	11.6	11.74945
16/09/1994	30	66.69753		25/08/1995	10.6	9.708995
18/09/1994	13	49.77529		27/08/1995	39.5	173.4957
14/06/1995	30	100.2317		28/08/1995	39.5	43.92944
16/06/1995	23	74.59807		29/08/1995	57	164.5588
17/06/1995	34.8	47.4138		31/08/1995	10	17.24346
20/06/1995	20.5	63.51857		01/09/1995	147.2	1201.931
21/06/1995	24.2	70.26386		02/09/1995	27.2	16.22748
23/06/1995	5.2	2.712486		03/09/1995	10	3.837825
26/06/1995	13	35.27133		04/09/1995	11.4	17.86967
01/07/1995	13.2	13.03389		05/09/1995	15.5	86.42625
02/07/1995	16.2	4.830771		11/09/1995	13.5	60.57963
03/07/1995	10	10.64596		12/09/1995	66	658.3142
08/07/1995	55.5	194.6571		15/09/1995	4.7	10.17174
09/07/1995	53.2	90.04178		18/09/1995	15.5	19.83357

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
22/09/1995	11.4	13.05742		08/08/1996	12.4	1.582718
23/09/1995	7.9	16.6291		09/08/1996	10	9.257704
24/09/1995	6.7	7.17183		10/08/1996	10	9.463431
30/09/1995	35.8	469.7973		11/08/1996	8.6	11.629
01/10/1995	20	23.7241		12/08/1996	18.5	12.27585
03/10/1995	15.5	18.50776		13/08/1996	18.1	21.46758
04/10/1995	14	14.25846		16/08/1996	14.5	24.02\4302
07/10/1995	12	68.97382		17/08/1996	13.9	18.19993
10/10/1995	46.3	260.6812		18/08/1996	9	13.30542
16/10/1995	10	47.42777		19/08/1996	20	34.90347
18/10/1995	38.5	237.0071		20/08/1996	10	2.149307
14/06/1996	26	146.5174		21/08/1996	14.6	36.5216
23/06/1996	50.5	136.0999		25/08/1996	37.2	200.3116
30/06/1996	46.8	179.9563		26/08/1996	30	142.7756
01/07/1996	55.5	156.4591		27/08/1996	42.2	149.7368
04/07/1996	20.4	46.51598		28/08/1996	29.5	53.20146
06/07/1996	17.4	57.15883		29/08/1996	14.5	5.366896
11/07/1996	38.2	121.1036		02/09/1996	7	15.3513
12/07/1996	107.5	1295.993		06/09/1996	10.5	28.22459
13/07/1996	26.8	29.59479		08/09/1996	10	25.63738
14/07/1996	42.5	101.2412		14/09/1996	26.3	55.31299
15/07/1996	105.8	379.7988		15/09/1996	34.5	64.38616
16/07/1996	120	913.6739		17/09/1996	6.5	6.330872
18/07/1996	0	1429.571		20/09/1996	11.2	33.50671
19/07/1996	62.4	177.3683		22/09/1996	18.4	58.49026
20/07/1996	10	6.932325		26/09/1996	23.2	41.42731
21/07/1996	117.2	495.8313		01/10/1996	10	3.837825
22/07/1996	113.5	524.453		02/10/1996	43.6	127.4137
23/07/1996	47.6	154.3655		03/10/1996	29.8	71.55261
24/07/1996	53.6	121.6023		20/10/1996	11	27.89468
25/07/1996	29.2	16.71138		21/10/1996	18	37.03082
26/07/1996	20	30.74069		22/10/1996	31.2	61.49479
27/07/1996	20	29.2056		25/10/1996	6	17.24346
28/07/1996	36.6	53.52964		10/06/1997	5.5	8.193368
29/07/1996	10	6.133595		13/06/1997	10	51.77197
30/07/1996	10	24.04302		14/06/1997	90	24.93819
31/07/1996	10	2.57875		15/06/1997	30	163.517
01/08/1996	10	8.557517		16/06/1997	75.5	830.7019
02/08/1996	10	6.326366		17/06/1997	28.5	18.27289
06/08/1996	20.6	60.81147		18/06/1997	110	1460.07
07/08/1996	10	21.46758		19/06/1997	150	1542.847

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
20/06/1997	57.5	409.033		21/08/1997	33.5	34.23171
21/06/1997	47.5	152.1109		22/08/1997	209	1762.71
23/06/1997	14.5	3.83825		23/08/1997	63.8	499.663
24/06/1997	55	650.4368		24/08/1997	27	37.76445
25/06/1997	16.5	6.932325		25/08/1997	46	92.8248
26/06/1997	25	32.34008		26/08/1997	59	229.1273
27/06/1997	59	509.7303		21/09/1997	8	14.28971
28/06/1997	71.5	393.5529		23/09/1997	10.5	30.26551
29/06/1997	20	30.98414		09/06/1998	19.7	28.55602
01/07/1997	10	37.03082		10/06/1998	46.5	69.44611
02/07/1997	24.5	41.62965		11/06/1998	15.1	9.257704
03/07/1997	10	9.257704		12/06/1998	8.3	16.6291
04/07/1997	10	51.77197		18/06/1998	61	539.9355
05/07/1997	80	231.2868		19/06/1998	16.5	14.8569
06/07/1997	62.5	295.5331		22/06/1998	10	9.936996
07/07/1997	153.5	1176.087		23/06/1998	82.3	636.0166
08/07/1997	99	442.749		24/06/1998	112	503.5416
12/07/1997	10	5.1575		26/06/1998	15.5	10.315
16/07/1997	12	23.43246		27/06/1998	80.5	444.889
17/07/1997	12	23.43246		28/06/1998	108.5	364.3283
20/07/1997	17	35.5153		29/06/1998	95.5	350.718
24/07/1997	24	68.48338		30/06/1998	92.1	347.8513
25/07/1997	10	12.05201		01/07/1998	22.9	11.29783
26/07/1997	121.5	685.3678		02/07/1998	64.2	217.5699
27/07/1997	56	123.7556		03/07/1998	30	44.16649
29/07/1997	116	651.7122		04/07/1998	39	45.42411
30/07/1997	43.2	68.65794		05/07/1998	22	7.908436
01/08/1997	30	40.29815		06/07/1998	15.5	9.2772
02/08/1997	32.5	106.0304		07/07/1998	58.5	322.4762
03/08/1997	8.8	7.17183		08/07/1998	56	151.0411
04/08/1997	31	31.63879		15/07/1998	32.2	69.72259
05/08/1997	22	32.92876		19/07/1998	15	34.83697
06/08/1997	39	42.17305		20/07/1998	14.4	13.82505
07/08/1997	49.5	98.63905		21/07/1998	9.4	5.283656
09/08/1997	19	61.12677		22/07/1998	9.8	10.315
11/08/1997	50	213.2184		25/07/1998	112.4	1053.562
12/08/1997	22	64.98403		26/07/1998	72.4	324.2131
13/08/1997	24.5	89.50583		27/07/1998	40.7	7.1783
14/08/1997	23	68.97382		29/07/1998	75	81.43744
19/08/1997	14	15.19506		31/07/1998	40	154.7309
20/08/1997	20.5	42.31233		02/08/1998	4	1.582718

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
03/08/1998	10	11.77769		09/10/1998	33	99.68237
04/08/1998	9.5	5.1575		10/10/1998	27	100.0629
05/08/1998	23.1	63.6063		11/10/1998	42	95.49221
06/08/1998	130	1012.841		12/10/1998	32	216.3957
07/08/1998	37.4	72.9237		14/10/1998	18	46.51598
08/08/1998	33.5	87.3429		16/10/1998	32	37.63093
09/08/1998	180	2234.458		18/10/1998	12	76.54244
10/08/1998	110	329.472		09/06/1999	20	42.78327
11/08/1998	14	5.366896		10/06/1999	46.05	79.23131
12/08/1998	20	7.17183		11/06/1999	15.1	16.37994
13/08/1998	30	21.07234		12/06/1999	7.3	16.06291
14/08/1998	38.5	309.5692		18/06/1999	60	803.9432
15/08/1998	33.5	64.71033		20/06/1999	16.5	14.8569
24/08/1998	10	28.68712		22/06/1999	10	6.721797
25/08/1998	30	247.2996		23/06/1999	82.9	619.0359
26/08/1998	70	461.2872		24/06/1999	112	1902.727
27/08/1998	42.5	36.72832		25/06/1999	4.4	1.58718
28/08/1998	37.7	37.77132		26/06/1999	15.5	12.20159
29/08/1998	20	61.84997		27/06/1999	80.5	492.4586
30/08/1998	5.7	7.17183		28/06/1999	108.5	365.0822
01/09/1998	11.5	15.3513		29/06/1999	146	307.6769
02/09/1998	7.5	14.28971		30/06/1999	92.2	348.0866
03/09/1998	6	17.24346		01/07/1999	22.9	21.24544
06/09/1998	9	20.09946		02/07/1999	64.1	198.1272
07/09/1998	34	268.0404		03/07/1999	30.5	28.85582
08/09/1998	14.5	14.28971		04/07/1999	39	67.97913
09/09/1998	29	53.26518		05/07/1999	22	7.318896
10/09/1998	35	41.46035		06/07/1999	15.5	9.110236
17/09/1998	43	635.5207		07/07/1999	58.5	327.1008
18/09/1998	10.5	8.193368		08/07/1999	56	150.8108
19/09/1998	30	167.9695		15/07/1999	32.1	53.55542
20/09/1998	21	96.88341		19/07/1999	15.5	54.32956
21/09/1998	10.5	12.05201		20/07/1999	14.4	9.257704
25/09/1998	19	67.0896		21/07/1999	9.4	5.366896
26/09/1998	26	88.92271		22/07/1999	9.5	12.55932
28/09/1998	10	17.24346		25/07/1999	102.5	1064.796
02/10/1998	18	68.97382		26/07/1999	72.3	273.1604
03/10/1998	22	59.4269		29/07/1999	75	57.56766
06/10/1998	52	487.1391		31/07/1999	40	135.2301
07/10/1998	30.5	319.9982		03/08/1999	10	18.93811
08/10/1998	34	37.0308		04/08/1999	9.5	2.57875

Date	P (mm)	R (MJ-mm/ha-hr-yr)		Date	P (mm)	R (MJ-mm/ha-hr-yr)
05/08/1999	23	26.76108		30/09/1999	17	321.434
06/08/1999	130	1004.107		02/10/1999	18.2	51.69176
07/08/1999	37.4	242.6116		03/10/1999	22.5	57.41066
08/08/1999	33.5	94.08656		06/10/1999	52	401.4624
09/08/1999	180	2249.453		07/10/1999	30.2	328.4505
10/08/1999	110	450.6852		08/10/1999	24	36.93932
11/08/1999	14	27.66991		09/10/1999	23	83.10718
12/08/1999	22.4	23.27003		10/10/1999	17	105.4684
13/08/1999	34.4	45.05088		11/10/1999	42.3	82.0242
14/08/1999	38.5	318.9402		12/10/1999	31.7	158.5908
15/08/1999	33.5	41.71027		14/10/1999	18.5	51.69176
17/08/1999	10	7.045048		16/10/1999	45	232.6654
24/08/1999	10	7.417512		17/10/1999	7.9	5.055133
25/08/1999	29.6	246.811		18/10/1999	14.1	70.22031
26/08/1999	70	456.5795		02/06/2000	5.4	13.73423
27/08/1999	42.5	97.64964		17/06/2000	6.3	2.149207
28/08/1999	37.7	45.85008		22/06/2000	16.5	26.4416
29/08/1999	20	52.89617		23/06/2000	20.5	30.07144
30/08/1999	5.6	7.045048		24/06/2000	3.9	0.975034
31/08/1999	10	6.58733		25/06/2000	60.5	169.7747
01/09/1999	11.4	13.72812		26/06/2000	8.6	37.4447
02/09/1999	5.6	13.19158		27/06/2000	56.4	184.0343
03/09/1999	3.8	7.959056		29/06/2000	28	17.45796
04/09/1999	3.8	3.837825		30/06/2000	20	2.76957
05/09/1999	5	0.58112		01/07/2000	43	91.78362
06/09/1999	9.5	18.27289		04/07/2000	41.9	177.7236
07/09/1999	32.6	258.8488		05/07/2000	98.4	303.5123
08/09/1999	14.3	15.12221		06/07/2000	144.7	298.2127
09/09/1999	28.4	59.50987		07/07/2000	235.2	3501.262
10/09/1999	35.2	45.25418		08/07/2000	160.1	982.6427
13/09/1999	5.5	2.57875		09/07/2000	83.2	338.088
14/09/1999	9.5	13.24648		11/07/2000	140	559.097
15/09/1999	4.3	4.477436		12/07/2000	130	693.5814
17/09/1999	43.1	75.02063		13/07/2000	22	9.872016
18/09/1999	10.5	12.45483		14/07/2000	17	9.154397
19/09/1999	19.4	113.2187		15/07/2000	16.5	8.812258
20/09/1999	20.9	98.74192		16/07/2000	18.5	53.23732
21/09/1999	10.8	11.23712		17/07/2000	15	5.1575
25/09/1999	18.8	62.04008		20/07/2000	9.4	2.57875
26/09/1999	26.5	87.91521		21/07/2000	12	6.210992
28/09/1999	9.1	13.20863		09/08/2000	74.2	277.6243

Date	P (mm)	R (MJ-mm/ha-hr-yr)
10/08/2000	138.2	896.3516
11/08/2000	45.9	143.1445
13/08/2000	6.5	3.781724
14/08/2000	2.5	2.481905
16/08/2000	9.5	24.66116
17/08/2000	11.5	46.51598
18/08/2000	27	48.56235
19/08/2000	24.5	64.30608
20/08/2000	29.1	43.91506
21/08/2000	52.6	62.85698
22/08/2000	50	92.9999
23/08/2000	22	13.15725
24/08/2000	101.5	1714.008
25/08/2000	44.9	53.88096
26/08/2000	78.5	173.7023
27/08/2000	174.1	828.49
28/08/2000	110	508.0979
29/08/2000	20	52.89617
30/08/2000	5.6	7.045048
31/08/2000	10	26.10267
01/09/2000	11.4	33.27892
09/09/2000	28.4	61.09877
10/09/2000	35.2	45.25418
13/09/2000	5.5	2.57875
14/09/2000	4.5	13.24648
15/09/2000	4.3	4.477463
17/09/2000	43.1	75.02063
18/09/2000	10.5	12.45483
19/09/2000	19.4	92.66815
20/09/2000	20.9	98.74195
21/09/2000	10.8	11.23712
25/09/2000	18.8	62.04008
26/09/2000	26.5	87.91521
27/09/2000	7.5	7.17183
01/10/2000	10	32.67444

APPENDIX II

Average annual rainfall (mm) of five rain gauge stations of Ratnagiri district

Year	Rainfall				
	Hedavi	**Karak**	**Poynar**	**Dapoli**	**Wakawali**
1984	2457.2	3934.1	3224	3016.4	3252.3
1985	3451.3	4166.8	4021	4861.9	4492.1
1986	1800.5	2960.7	2684.7	2403.9	2766.6
1987	4201.1	3437.4	3372.2	2398.3	3670.4
1988	2802.8	4583.8	3810.4	3444.3	3933
1989	3571.3	3856.5	3119.5	3188.6	3367.8
1990	3289.5	4113.5	4180.1	5070.2	3993
1991	2703.84	3600.7	3778.3	3766.9	3720
1992	2768	3706	3146.3	2990.5	2914.9
1993	4871.4	4330.6	4424.7	3843.2	4533
1994	3399.9	4366.3	3277.9	2905.5	3064.5
1995	3222.7	3576.5	3412.1	3100.2	2984.2
1996	3336.1	3312.6	3200.3	3108.5	2970.2
1997	3252.4	4385.4	3174.6	3720	3505.9
1998	3953.8	4555.7	3279.71	3786.2	3451.6
1999	2521	3954.3	3207.3	4059.8	3319.9
2000	4817.9	3508.3	3742.2	4416.35	3574.6
2001	2296.1	3389.2	2381.4	2323.3	4091.1
2002	2146.05	3249.9	2851.2	2712.5	4078.8
2003	2924.2	3010	3188	3004.6	3382.9
2004	3203	3944.93	3530.33	3439.7	3434.9
2005	4308.4	5003.97	4380.99	3650.8	4063.1
2006	3033	4790.2	3859	3361.2	3848.4
2007	3450	4609.9	4011.5	4243.37	4217.2
2008	2959.3	4094.8	3301.5	2988.8	4099.9
2009	3092.8	3516.4	2825.8	2566.5	3125.4
2010	5902.6	4258.6	3980.9	4631.4	3900.3
2011	4224	5267	4754.6	4928.8	4650.3
Average	**3355.72**	**3981**	**3504**	**3497.56**	**3657.36**

APPENDIX III

Textural, Structural and Permeability classes and codes of soils of Ratnagiri district

Sr. No.	Villages	Tehsil	Textural class	Structure class	Structure code	Permeability Class	Permeability code
1	Nachne	Ratnagiri	Textural class	Moderate	3	Moderate To Rapid	2
2	Jaygad		Silty loam	Moderate	3	Moderate To Rapid	2
3	Vasani		Loam	Moderate	3	Moderate To Rapid	2
4	Ganpatipule		Loam	Moderate	3	Moderate To Rapid	2
5	Jambhrun		Loam	Moderate	3	Moderate To Rapid	2
6	Gavane	Lanja	Loam	Moderate	3	Moderate To Rapid	2
7	Khan Vali		Loam	Moderate	3	Moderate To Rapid	2
8	Agave		Sandy loam	Moderate	3	Moderate To Rapid	2
9	Kurne		Clay loam	Moderate	3	Moderate To Rapid	2
10	Harche		Loam	Moderate	3	Moderate To Rapid	2
11	Jaitapur	Rajapur	Sandy clay loam	Moderate	3	Moderate To Rapid	2
12	Nanar		Loam	Moderate	3	Moderate To Rapid	2
13	Niveli		Loam	Moderate	3	Moderate To Rapid	2
14	MithGavane		Loam	Moderate	3	Moderate To Rapid	2
15	Sagve		Sandy clay loam	Moderate	3	Moderate To Rapid	2
16	Pimpali	Chiplun	Loam	Moderate	3	Moderate To Rapid	2
17	Savarde		Loam	Moderate	3	Moderate To Rapid	2
18	Tiwre		Loam	Moderate	3	Moderate To Rapid	2
19	Dhameli		Loam	Moderate	3	Moderate To Rapid	2
20	Bamnoli		Loam	Moderate	3	Moderate To Rapid	2

Appendix III Contd…

Sr. No.	Villages	Tehsil	Textural class	Structure class	Structure code	Permeability Class	Permeability code
21	Nive	Sangmeshwar	Clay loam	Moderate	3	Moderate To Rapid	2
22	Ozare		Loam	Moderate	3	Moderate To Rapid	2
23	Sakharpa		Loam	Moderate	3	Moderate To Rapid	2
24	Dhamapur		Loam	Moderate	3	Moderate To Rapid	2
25	Tulsani		Loam	Moderate	3	Moderate To Rapid	2
26	Chikhli	Guhagar	Loam	Moderate	3	Moderate To Rapid	2
27	Abloli		Silty loam	Moderate	3	Moderate To Rapid	2
28	Naravan		Loam	Moderate	3	Moderate To Rapid	2
29	Pomendi		Loam	Moderate	3	Moderate To Rapid	2
30	Kotaluk		Loam	Moderate	3	Moderate To Rapid	2
31	Lote	Khed	Loam	Moderate	3	Moderate To Rapid	2
32	Khopi		Loam	Moderate	3	Moderate To Rapid	2
33	Kudeshi		Loam	Moderate	3	Moderate To Rapid	2
34	Sukavali		Loam	Moderate	3	Moderate To Rapid	2
35	Musad		Loam	Moderate	3	Moderate To Rapid	2
36	Kumbale	Mandangad	Sandy clay loam	Moderate	3	Moderate To Rapid	2
37	Surle		Loam	Moderate	3	Moderate To Rapid	2
38	Kuduk		Sandy Loam	Moderate	3	Moderate To Rapid	2
39	Pimpoli		Clay Loam	Moderate	3	Rapid	1
40	Ranvali		Sandy clay loam	Moderate	3	Moderate To Rapid	2
41	Shirsoli	Dapoli	Loam	Moderate	3	Moderate To Rapid	2
42	Burondi		Loam	Moderate	3	Moderate To Rapid	2
43	Unhavare		Silty loam	Moderate	3	Moderate To Rapid	2
44	Gavhe		Sandy clay	Moderate	3	Moderate To	2

			loam			Rapid	
45	Avashi		Silty loam	Moderate	3	Moderate To Rapid	2

APPENDIX IV

Erodibility of soils of Ratnagiri district

Sr. No.	Villages	Tehsil	%Sand	%Silt	% Clay	% O.C.	H.C. (cm/hr)	M	a (O.M.)	b	c	K (t-ha-hr/ha-MJ-mm)
1	Nachne	Ratnagiri	35.53	51.16	13.31	1.14	6.14	6591.13	2	3	2	0.064
2	Jaygad		39.19	47.84	12.97	1.77	23.57	6551.01	3.1	3	2	0.056
3	Vasani		44.01	40.25	15.74	1.61	4.49	5987.26	2.8	3	2	0.053
4	Ganpatipule		33.81	43.65	22.54	1.9	16.23	5214.37	3.3	3	2	0.043
5	Jambhrun		37.68	41.68	20.64	1.98	11.78	5400.92	3.4	3	2	0.044
6	Gavane	Lanja	33.81	43.65	22.54	1.77	16.43	5214.37	3.1	3	2	0.044
7	Khan Vali		52.77	31.85	15.54	0.93	8.25	5809.92	1.6	3	2	0.057
8	Agave		38	36.38	25.62	1.16	20	4684.45	2	3	2	0.043
9	Kurne		45.73	32.42	21.85	1.48	6.04	5035.28	2.6	3	2	0.044
10	Harche		44.62	26.04	29.34	1.43	9.32	4046.98	2.5	3	2	0.035
11	Jaitapur	Rajapur	46.15	40.67	13.18	1.19	3.17	6335.69	2.1	3	2	0.06
12	Nanar		43.1	38.55	18.35	1.72	15.29	5610.99	3	3	2	0.048
13	Niveli		50.66	32.83	16.51	1.46	15.62	5701.7	2.5	3	2	0.051
14	MithGavane		62.7	13.49	23.81	1.3	6.9	4371.78	2.2	3	2	0.039
15	Sagve		40	43.63	16.37	1.48	9.01	5990.42	2.6	3	2	0.054
16	Pimpali	Chiplun	45.04	38.77	16.19	1.71	3.6	5891.68	2.9	3	2	0.051
17	Savarde		47.82	28.76	23.42	1.4	5.13	4765.88	2.4	3	2	0.042
18	Tiwre		30.64	45.16	24.2	1.46	20.82	5048.89	2.5	3	2	0.045
19	Dhameli		48.31	27.32	24.37	1.63	5.38	4623.79	2.8	3	2	0.039
20	Bamnoli		38.78	31.82	29.4	1.04	14.68	4163	1.8	3	2	0.039

Appendix IV Contd…

Sr. No.	Villages	Tehsil	%Sand	%Silt	% Clay	% O.C.	H.C. (cm/hr)	M	a (O.M.)	b	c	K (t-ha-hr/ha-MJ-mm)
21	Nive	Sangmeshwer	47.72	37.96	14.32	1.81	16.15	6114.47	3.1	3	2	0.052
22	Ozare		47.4	33.54	19.06	1.16	11.86	5400.32	2	3	2	0.051
23	Sakharpa		36.76	37.33	25.91	1.15	15.13	4672.26	2	3	2	0.043
24	Dhamapur		48.45	27.15	24.4	1.37	5.41	4616.51	2.4	3	2	0.041
25	Tulsani		40.87	42.37	16.76	1.19	5.79	5908.29	2.1	3	2	0.056
26	Chikhli	Guhagar	32.42	51.01	16.57	1.51	7.39	6149.12	2.6	3	2	0.055
27	Abloli		41.16	40.14	18.7	1.49	24.1	5605.8	2.6	3	2	0.05
28	Naravan		35.1	46.31	18.59	1.37	2.64	5770.34	2.4	3	2	0.053
29	Pomendi		38.75	39.66	21.59	1.5	11.45	5236.61	2.6	3	2	0.046
30	Kotluk		48.49	34.13	17.38	0.83	5.05	5624.19	1.4	3	2	0.056
31	Lote	Khed	46.01	34.74	19.25	1.6	7.67	5405.97	2.8	3	2	0.047
32	Khopi		38.42	43.49	18.09	1.92	18.92	5765.15	3.3	3	2	0.048
33	Kudeshi		47.84	31.97	20.19	0.14	6.17	5224.2	0.2	3	2	0.057
34	Sukavali		48.16	28.23	23.61	1.02	5.46	4731.75	1.8	3	2	0.045
35	Musad		56.89	22.11	21	1.04	13.53	4892.71	1.8	3	2	0.046
36	Kumbale	Mandangad	42.46	41.67	15.87	1.69	4.82	6006.21	2.9	3	2	0.052
37	Surle		59.94	20.61	19.45	1.12	20.87	5039.85	1.9	3	2	0.047
38	Kuduk		37.21	33.21	29.34	1.58	15.51	4187.1	2.7	3	2	0.036
39	Pimpaloli		55.65	18.67	25.68	1.36	25.32	4282.69	2.3	3	1	0.035
40	Ranvali		36.82	39.44	23.74	1.3	14.22	4973.22	2.2	3	2	0.045
41	Shirsoli	Dapoli	40.94	40.5	18.56	1.1	22.55	5632.23	1.9	3	2	0.054
42	Burondi		23.73	51.03	25.24	1.16	3.17	5056.84	2	3	2	0.047
43	Unhavare		52.86	23.85	23.29	1.29	2.84	4667.96	2.2	3	2	0.042
44	Gavhe		28.07	52.16	19.77	1.63	23.64	5761.24	2.8	3	2	0.05
45	Avashi		42.1	38.3	19.6	1.41	8.45	5448.71	2.4	3	2	0.049

APPENIDIXV

Crop management factor of study area

$$Weighted\ C = \frac{C_1 A_1 + C_2 A_2 + C_3 A_3}{A_1 + A_2 + A_3}$$

$$Weighted\ C = \frac{0.15 * 92616 + 0.10 * 163310 + 0.28 * 143}{92616 + 163310 + 143}$$

$$Weighted\ C = 0.12$$

LU/LC class	Area (ha)	C value	Weighted C
Rice, Nagali, Pulses	**92616**	0.15	0.12
Horticultural crops	**163310**	0.10	
1. Mango	65386		
2. Cashew	91381		
3. Coconut	5179		
4. Sapota	124		
5. Arecanut	965		
6. Maize	114		
7. Others	161		
Oil seeds	**143**	0.28	

APPENDIX VI

Estimation of tolerable soil loss

1. Relationship between loss of yield and loss of topsoil

$$\mathrm{TL} = \frac{\left(\left(\frac{\mathrm{Ra}}{\mathrm{Rm}} * 100 * \mathrm{BD} * \mathrm{D}\right) + 3\mathrm{T}\right)}{\mathrm{T}}$$

Where, TL = tolerable soil loss rate (t/ha/yr),

Ra = the acceptable yield reduction (%),

Rm = the yield reduction (%) at the given input level when the effective topsoil was lost,

BD = bulk density of soil (Mg/m^3),

D = depth of effective topsoil (cm),

T = time (years) overwhich reduction was acceptable

$$\mathrm{TL} = \frac{\left(\left(\frac{50}{25} * 100 * 1.26 * 25\right) + (3 * 100)\right)}{100}$$

$$\mathrm{TL} = 66.00 \text{ t/ha/yr.}$$

2. Proportion of land that can be allow to make the soil shallower at least by one soil depth class over a specified time period.

$$\mathrm{P} = \frac{\mathrm{SL} * \mathrm{T}}{\mathrm{BD} * \mathrm{D}}$$

Where, P = proportion of land downgraded to at least the next depth class (%),

SL = soil loss (t/ha/yr),

T = time (years),

BD = bulk density of the soil (Mg/m^3),

D = depth range of soil class (cm)

$$10 = \frac{\mathrm{SL} * 100}{1.26 * 25}$$

$$\mathrm{SL} = 3.15 \text{t/ha/yr.}$$

APPENDIX VII

Curriculum Vitae

Ms.SalunkheSanjani Sunil.

Department of Soil and Water Conservation Engineering.
CAET, Dapoli- 415712
Phone- 9404743607

Email-sanjanisalunkhe@gmail.com

EducationalQualification:

Examination Passed	Percentage/CGPA	Board/University	Yearof Passing
M.Tech(SWCE)	Appeared	Dr.B.S.K.K.V, Dapoli	2017
B.Tech (Agril. Engg.)	8.16	Dr.B.S.K.K.V, Dapoli	2015
H.S.C.	66.00	Kolhapur	2011
S.S.C.	78.00	Kolhapur	2009

Professional Trainings:

Organization	Duration	Natureof work
Central Farm Machinery Training & Testing Institute, Budhani, MP.	1 Month	Operation & Maintenance of Tractor
Central Soil and Water Conservation Research and Training Institute, Udagmandalam, TN.	1 Month	Different laboratory tests of soil.

In-Plant Training:

Organization	Duration	Natureof work
Netafim Irrigation India Pvt. Ltd., Kothrud, Pune.	4 Month	AutoCAD based Micro Irrigation System Design (Surface, sub-surface and greenhouse designs).

Thesis/Research Project:

- **Under Graduate project:**

Title: - “Effect of Various Filtration Media on Grey Water.

- **Post Graduate project:**

Title: - “Soil Erosion and Crop Productivity Model for Ratnagiri District using RS and GIS.”

Industrial/Institute Training:

Organization	Duration	Natureof work
Aditi Infotech Pvt. Ltd., Dhantoli, Nagpur	1 Month	Working on Image Processing and GIS Softwares (Digitization, DEM processing and classification methods).

Proficiency andSkills:

1. Completed certified course in MS-CIT.
2. Proficiency in application of RS and GIS softwares.
3. Proficiency in design softwares - AutoCAD, Pro/E.

Extracurricularachievements:

1. Represented University in Inter-University Sports Tournament (Ashvamedha) 2012, 2013, 2015.
2. Winnerof state level Engineering Project Competition "DIPEX 2017".
3. Completed NSS camp 2014-2015.
4. Active participation in Social activities like tree plantation, Blood donation.

Hobbies:

- Drawing, playing sports.

PersonalInformation:

PermanentAddress: SalunkheSanjani Sunil.
A/P Kusur,
Tal-Vaibhavwadi,
Dist-Sindhudurg
Pin- 416 813

Dateofbirth: 22nd July 1993
Gender: Female
MaritalStatus: Unmarried
Languagesknown: English, Hindi, Marathi

Declaration:

Iherebydeclarethat theinformationfurnished aboveistruetothebestof myknowledge.

Date: **(SalunkheSanjani Sunil)**

SOIL EROSION AND CROP PRODUCTIVITY MODEL FOR RATNAGIRI DISTRICT

A Thesis submitted to

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)

In the partial fulfillment of the requirements for the degree
of
MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)
in
SOIL AND WATER CONSERVATION ENGINEERING
by

Miss. Salunkhe Sanjani Sunil
(ENDPM 2015/098)

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College of Agricultural Engineering
and Technology, Dapoli.

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part there of has not been submitted

by me or any other person to any other

University or Institute

For a Degree or

Diploma

Place: Dapoli **(Sanjani S. Salunkhe)**

Dated: **/** /2017 **ENDPM 2015/098**

Prof. dilip MAHALE.
B. Tech. (Agril. Engg.), M. Tech. (SWCE)
Chairman and Research Guide,
Professor and Head,
Department of Soil and Water Conservation Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the thesis entitled **"Soil Erosion and Crop Productivity Model for Ratnagiri District"** submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist.- Ratnagiri, (Maharashtra State) in the partial fulfilment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Soil and Water Conservation Engineering,** embodies the results of bonafide research work carried out by **Ms. Sanjani Sunil Salunkhe (ENDPM 2015/098)** under my guidance and supervision. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place: Dapoli
Dated: / /2017 **(dilip MAHALE)**

Dr. Y. P. Khandetod
B.Tech. (Agril. Engg.), M. Tech. (P.H.E.), Ph.D. (AGFE)

Dean,
Faculty of Agricultural Engineering,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the thesis entitled **"Soil Erosion and Crop Productivity Model for Ratnagiri District"**submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist.- Ratnagiri, (Maharashtra State) in the partial fulfilment of the requirements for the award of the degree of Master of Technology (Agricultural Engineering) in Soil and Water Conservation Engineering is a record of bonafide research work carried out by **Miss. Sanjani Sunil Salunkhe (ENDPM 2015/098)** under the guidance and supervision of **Prof. dilip MAHALE,** Professor and Head, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place: Dapoli **(Y. P. Khandetod)**

Dated: / /2017

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Definitely success can be achieved by hard work and sincere efforts. But behind this success there is knowing and unknowing involvement of many innovative minds and creative hands to beautify it. Emotions cannot be adequately expressed in words because then emotions are transferred into mere formalities. Nevertheless, formalities have to be completed. My acknowledgement are many more than what I am expressing here.

I wish to extend my sincerest thanks and appreciation to all those who have helped and supported me all throughout my endeavour. First and for most, I wish to express my earnest regards and gratitude to my mentor ***Prof. dilip MAHALE,*** *Professor and Head****,*** *Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dapoli for his valuable guidance, timely suggestion and constant encouragement throughout the research work.*

It mention my sincere gratitude to respected ***Dr. Y. P. Khandetod,*** *Dean, Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli who gave me an opportunity for undergoing this research work providing necessary facilities for whenever needed.*

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I am equally indebted to, ***Dr. K. D. Gharde,*** *Assistant Professor, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dapoli for their valuabe advice and constant cooperation throughout my project work.*

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But for the affection, words of encouragement, boundless love, unflagging inspiration, interest and selfless sacrifice for me, I would not have been what I am today. A great deal of credit goes to all my family members here, especially ***Aai-Baba, sister*** *and* ***brother****. There are no words to express my feelings for them.*

Words in my command are inadequate to express my heartfelt thanks to my seniors ***Sangita di, Nayana di****,* ***Ganesh sir*** *and also my friends specially* ***Tejashri*** *and* ***Pooja, Shalaka, Punam, Manisha, Adwait, Dnyaneshwar, Rajan*** *and* ***Sagar*** *for their everlasting encouragement during carrying out this work and untiring help rendered with cheerful smiling gestures.*

The acknowledgement cannot be completed without mentioning my cordial gratitude thanks to all those, who helped me knowingly or unknowingly in this study.

Place: Dapoli **(Sanjani S. Salunkhe)**

Dated: / /2017 **ENDPM 2015/098**

I. INTRODUCTION

Plant growth majorly depends on soil and water which are two important natural resources. Soil erosion is a growing problem especially in areas of agricultural activity where soil erosion not only leads to decreased agricultural productivity but also reduces water availability. So one of the reasons for low productivity is progressive deterioration of soil due to erosion.

Soil erosion is the process of detachment and transportation of surface soil particles from original location and accumulation of it to new depositional area. Agencies or the energy sources involved in the process of soil erosion are mainly water, wind, sea waves, human beings and animals (Jose *et al*., 2015). Soil erosion as "soil cancer" is a complex process and its multiple obvious and hidden social and environmental impacts are an increasing threat for the human existence (Ownegh and Nohtani, 2004).

The rates of soil erosion that exceed the generation of new topsoil are a dynamic process which leads to decline in the soil productivity, low agricultural yield and income. The balance between soil-forming and depleting processes is of utmost importance for attaining long-term sustainability in any production system (Kumar and Pani, 2013).

Soil degradation by accelerated erosion is a serious problem and will remain so during the 21st century and its severity and economic and environmental impacts are debatable (Lal, 2001). Soil erosion on cultivated lands has received much concern since it is considered to be one of the most critical forms of degradation (Montgomery, 2007)

In recent years, soil degradation has reached alarming proportions in many parts of the world, especially in the tropics and sub-tropics. The estimates suggest that globally about 24 bt (billion tonne) of soil is lost annually through water erosion in excess of the natural rate of soil regeneration. According to FAO, about 18% of the arable lands in the world could be lost for ever if no measures are taken to preserve them. About 30–50% of the world's arable lands are substantially degraded due to soil erosion, which directly affects rural livelihood. Soil erosion caused by water is a major factor contributing to land degradation in India and many other countries, as it far exceeds the natural soil formation rates. India loses about 16.4 t/ha/yr of soil, of

which 29% is lost permanently into the sea, 10% gets deposited in the reservoirs reducing their capacity by 1–2% every year and the remaining 61% gets displaced from one place to another (Mandal and Sharda, 2011).

Our country faces major challenges to increase its food production to the tune of 300 million tons by 2020 in order to feed its ever-growing population, which is likely to reach 1.30 billion by the year 2020. To meet the demand for food from this increased population, the country's farmers need to produce 50 % more grain by 2020 (Paroda and Kumar, 2000) .Unfortunately, there are evidences of stagnation in yield growth rates of majority of food crops in recent decades.

In India, about 53% of the total land area is prone to erosion and has been estimated that about 5,334 million tonnes of soil is being detached annually due to various reasons (Narayana and Babu, 1983). Soil degradation in India is estimated to be occurring on 147 million hectares (Mha) of land, including 94 Mha from water erosion, 16 Mha from acidification, 14 Mha from flooding, 9 Mha from wind erosion, 6 Mha from salinity and 7 Mha from a combination of factors (Bhattacharyya *et al*., 2015). Maharashtra is also facing similar level of severity in soil erosion. The quantity of soil erosion per year in Maharashtra is 773.5 m tons and 94 % of that erosion is water induced (Durbude, 2015).

Assessment of soil erosion is an expensive and intensively long exercise. A number of parametric models have been developed to forecast soil erosion at drainage basins. Universal Soil Loss Equation i. e. USLE (Wischmeier and Smith, 1978) is the most popular empirically based model used globally for erosion prediction and control. The various factors of USLE are rainfall erosivity factor (R), soil erodibility factor (K), length and steepness of slope factor (LS), vegetation and crop cover factor (C) and conservation practice factor (P).

However, this soil erosion needs to be coupled with soil formation process through pedogenesis. So overall soil erosion and related productivity loss of land is complex phenomena involving soil erosion, soil formation, input applications and environmental conditions. It demands multidisciplinary study of all aspects to get realistic view of relationship between soil loss and productivity loss of the region.

For developing suitable soil conservation strategies, knowledge of the prevailing and permissible rates of soil erosion is an essential prerequisite. Tolerable soil loss is a concept developed in the 20^{th} century and it is useful to judge if a soil has potential risk of erosion, productivity loss and off-site damages. The acceptable rate of soil erosion (T-value) is defined as the maximum amount of erosion at which the quality of a soil as a medium for plant growth can be maintained. Quantifying the acceptable soil loss without affecting crop productivity is a major challenge for researchers, planners, conservationists and environmentalists. If the erosion exceeds the value, it adversely affects productivity and must be brought down within the permissible rate to ensure sustainability of a production system.

Conservation objectives for soil loss tolerance are based on maintaining a suitable seedbed and nutrient supply in the surface soil, maintaining adequate depth and quality of the root zone, and minimizing unfavourable changes in water availability throughout the soil.

This kind of study is very essential in Konkan region of Maharashtra due to extreme weather conditions and huge loss of soil through runoff. In the coastal zone of Ratnagiri, most of the agricultural lands along the banks of the estuaries or near the sea are converted to saline land also called as kharlands. It is part of Western Ghats which comes under one of 34 world biodiversity hotspots (Myers *et al*., 2000 and Chitale *et al*., 2015). So Ratnagiri district is ecologically sensitive region where natural resources need to be protected with maximum care. The application of Remote Sensing and GIS is most suitable technique for coastal resource management. GIS based analysis gives better results and effective strategies for the mitigation of such affected coastal zones. However, due to hilly terrain of Sahyadri ranges, data availability or accessibility is scare.

Efficient management of natural resources viz. soil and water is the major challenge for the agricultural scientists, planners, administrators and farmers to ensure food, water and environmental security for the present and future generations. Soil is the essence of life. An intimate knowledge on their characteristics, classification, location, extent and distribution, potentials and problems is a prerequisite for developing rational land use planning. Soil resource inventory provides an insight into the potentialities and limitation of soil for its effective exploitation. Modern tools such as satellite Remote Sensing (RS), Global Positioning System (GPS) and Geographical Information System (GIS) have been providing newer dimensions to monitor and manage soil resources for their effective utilization. Especially remote sensing techniques have reduced our field work to a considerable extent and soil boundaries are more precisely delineated than in conventional methods. Hence, it is a highly proven technology that is effective for mapping and characterizing land resources.

The RS and GIS techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage (Parveen and Kumar, 2012). With the advance of Remote Sensing technique (RS) it becomes possible to measure hydrologic parameters on spatial scales while Geographic Information System (GIS) integrates the spatial and analytical functionality for spatially distributed data. The combined use of GIS and erosion model, such as USLE, has been proved to be an effective approach for estimating the magnitude and spatial distribution of erosion.

Data collected through Remote Sensing technique (RS) and GIS is also helpful in study of land-use pattern and analysis relating the soil loss with loss of yield. In this content study entitled “Soil erosion and crop productivity model for Ratnagiri District” is undertaken with following objectives:-

1. Development of various thematic maps of land-use pattern and soil-site characterization.
2. Estimation of soil loss using Universal Soil Loss Equation (USLE).
3. Development of relationship between loss of yield and loss of topsoil.
4. Estimation of productivity and tolerable soil loss.

II. REVIEW OF LITERATURE

This chapter deals with the review of study carried out by various investigators on the applications of Remote Sensing (RS) and Geographical Information System (GIS), estimation of soil erosion by USLE, relationship between loss of yield and loss of topsoil and also estimation of tolerable soil loss.

2.1 Development of various thematic maps of land-use pattern and soil-site characterization

Chakraborty *et al*. (2001) studied the vegetation dynamics and land use/land cover types of Birantiya Kalan watershed located in the arid tracts of western Rajasthan have been characterized and evaluated using RS and GIS. The result showed that the land with scrub occupied maximum area (39% area of the watershed) in 1996 in place of crop land which was dominant (43% of total area) in the year 1988. During eight years period, seasonal fallow land increased significantly and the areal extent of water body decreased to almost half. Vegetation vigour types have been classified into very poor, poor, moderate, good and very good categories. Moderate vigour type reduced from 62 to 27% and poor type increased from 34 to 68% during the period 1988 to 1996. It has been observed that the ratio for vegetation vigour has been found to be 0.85 showing that the overall vegetation has not improved after the treatment. The ratio for land use is found to be 1.01, which indicates negligible change in land use.

Bobade *et al*. (2010) carried out land evaluation for agricultural planning in Seoni district in Madhya Pradesh, India. The soil-based GIS data was compiled and interpreted for land use suitability and fertility assessment. Maps of fertility and land use suitability were generated from interpretative records. The land use suitability analysis indicated that 44% of land was non-arable and was found to be suitable for silvipasture and wildlife conservation and 56% of land was arable, of which, 24% was found to be suitable for sorghum-soybean and 15% for sorghum-cotton systems that can be productive despite a deficiency of potassium and zinc. The remaining 18% area was recommended for rice, citrus, maize, sunflower and vegetables.

Panigrahy *et al*. (2010) studied the forest cover change detection of Western Ghats of Maharashtra using satellite remote sensing based visual interpretation technique over a 20-year time period (1985–87 to 2005). The study was conducted using the Forest Survey of India vegetation maps for 1985–87, prepared using Landsat TM data and IRS LISS III imagery for 2005. The results reveal that loss of dense forest at an annual rate of 0.72% and that of open forest at 0.49%. It also reports an increase in mangrove vegetation and water bodies in the study area. In addition, it also reports district wise pattern of change in forest cover.

Anil *et al*. (2011) studied the changes in land use/ land cover of South West Godavari district, Andhra Pradesh using RS and GIS techniques. The study was carried out through RS and GIS approach using SOI toposheets, Landsat imagery of 2000 and IRS-1D-LISS-III 2010. The result showed that there were some changes detected in land use/land cover analysis of the period 2000-2010, it does not indicate any significant environmental impact on the study area. However, it was necessary to closely monitor the land use/land cover changes for maintaining a sustainable environment.

Hu *et al*. (2012) carried out the analysis of land use change characteristics in the Jiuxiang river watershed Nanjing city, China, based on RS and GIS technology. Results showed that watershed land use structure were changed greatly from 2003 to 2009, the proportion of arable land decreased from 34.86% to 19.52%, whereas other types of land use increased. The area of construction land was increased most rapidly, from 17.80% to 25.80%. The arable land was mainly converted to forestland and grassland in upstream region, and was mainly converted to construction land and forestland in midstream region. However, in downstream region, this type of land use was mainly converted to construction land. High farmland conversion rate in current period was contributed to rapid urbanization in Jiuxiang River watershed. Therefore, some measures must be initiated to achieve land resources sustainable use.

Kotoky *et al*. (2012) studied the changes in land use and land cover along the Dhansiri river channel, Assam using RS and GIS for the period of 33 years during 1975 to 2008. The result shows that significant reduction (13.02%) in cropland area to settlement was observed. Moreover, teagarden also occupies 0.77% of the total area from cropland and open mixed jungle. It was believed that the present study was helpful to contribute towards sustainable land-use planning and management towards protection of extremely rich biodiversity of the North East India with mighty Brahmaputra River system.

Chopra (2012) studied the land resources in the region south of the River Son, Sonbhadra District, U.P. Maps on various themes, Land Use/Land Cover, Geomorphic Units, Soils, Ground Water Potential and Environmental Degradation have been generated using aforementioned satellite data coupled with ground truth. All these maps were critically evaluated and the problem areas were identified and land use plan has been suggested for the overall development of the study area.

Sarma *et al*. (2012) studied the Umtrew river basin spreading over the Indian states of Meghalaya and Assam, RS and GIS techniques have been used to analyse the basin characteristics. Various thematic maps like contour, drainage, road network, settlement, land capability and land use/land cover have been prepared to highlight the present scenario of the study site. Satellite image of 2004, 2007 and 2010 were used to understand the land use/land cover change in the basin area. Result shows that there was a decrease of 5.93% of semi evergreen forest from 2004 to 2010.

Das *et al.* (2014) carried out characterization and evaluation of land resources of Mawryngkneng block in Meghalaya using IRS-P6 LISS III and LISS-IV data. Five major physiographic units namely structural hills, denudational hills, plateau and intermountain valley were identified. Visual interpretation of satellite data indicated that 32.2% of the total geographical area (TGA) is under dense forest followed by wastelands (28.8%), open forest (16.1%), cultivated area (13.6%), built up area (8.2%) and water body (0.9%). An action plan with suggested land use and interventions has been prepared that action plan includes areas for afforestation, intensive cultivation in the existing cropped areas with soil conservation measures like mulching, zero tillage etc. and orange and pine apple plantation in open scrub lands which are cultivable wastelands.

Jayanti (2014) carried out characterization and evaluation of land resources of watershed using IRS-P6-LISS-III, Katihar district of Bihar. Visual interpretation of satellite data indicated that about 60 % of the total geographical area was under cultivation followed by waterlogged, ox-bows and scrubs. Six soil series were tentatively identified. On the basis of reconnaissance soil survey, Gola-Pachgachhia, Bhatgaon-Balrampur, Khamber-Pachgachhia and Nohri-Khamber Soil Association map of the district has been developed. An action plan has also been prepared with suggested land use and appropriate interventions which might help in better management of land resources for sustained productivity.

Vikhe and Patil (2016) studied the land use/ land cover classification and change detection using GIS in Sukhana Basin of Aurangabad District, Maharashtra. The tools used ArcGIS10.1 and ERDAS IMAGINE 9.1, Landsat images of 1996, 2003 and 2014. From land use / land cover change detection it was found that during 1996-2014, water bodies cover have loss of 4 sq. km., barren land have 146 sq. km. loss and forest area with 96 sq. km. loss. It was also found that urbanization area has gain of 51 sq. km. and agricultural land cover has gain of 195 sq. km.

2.2 Estimation of soil loss using USLE

Potdar *et al*. (2003) studied the erosional soil loss in Nanda-Khairi watershed of Nagpur district of Maharashtra. The result concluded that nearly 62 % area of the watershed was under slight erosion. The moderately slight erosion and moderate erosion covered 28.10% and 0.4% area of the watershed, respectively. The area under moderately severe and very severely erosion classes covered 6.5% and 1.0 % area, respectively.

Dabral *et al*. (2008) carried out soil erosion assessment of Dikrong river basin of Arunachal Pradesh, India. The average rainfall erositivity factor (R) was found to be 1,894.6 MJ mm/ha/h/yr. The soil erodibility factor (K) with a magnitude of 0.055 t-ha-h/ha/MJ/mm and 0.039 t-ha-h/ha/MJ/mm highest and lowest value respectively and also slope length factor (LS) were 53.5 and 5.39. The highest and lowest values of crop management factor (C) were found out to be 1.0 and 0.004 respectively and conservation factor (P) 1 and 0.28. Estimated average annual soil loss of the Dikrong river basin was 51 t/ha/year. About 25.61% of the watershed area was found out to be under slight erosion class.

Subhash *et al.* (2009) estimated the annual soil loss rate in the Kudremukh national park, Karnataka. The estimation was done by applied the USLE to 219 watersheds, to demonstrate its applicability and usefulness. The results obtained that, 67 micro watersheds lies in nil to slight, 77 micro watersheds lies in slight to moderate and 75 micro watersheds lies in moderate soil erosion, but no severe and very severe soil erosion was noticed in this region.

Nagaraju *et al*. (2011) studied the soil loss mapping for sustainable development and management of land resourses in Warora Tehsil of Chandrapur district of Mabarashtra. Spatial information related to existing geology, land use/land cover, physiography, slope and soils has been derived through remote sensing, collateral data and field survey and used as of inputs in a widely used erosion model (Universal Soil Loss Equation) in India to compute soil loss (t/ha/year) in GIS. The study area has been delineated into very slight (<5 t/ha/year), slight (5–10 t/ha/year), moderate (10– 15 t/ha/year), moderately severe (15–20 t/ha/year), severe (20–40 t/ha/year) and very severe (>40 t/ha/year) soil erosion classes. The study indicated that 45.4 thousand ha. (13.7% of TGA) was under moderate, moderately severe, severe and very severe soil erosion categories.

Sheikh *et al.* (2011) estimated the soil erosion of Lidder Catchment in Himalayan region using Universal Soil Loss Equation (USLE) erosion model and GIS. The annual soil loss predictions range between 0 and 61 t/ha/year. Average soil loss was highest (26 t/ha/year) in agriculture area and lowest soil loss rate was found in forest area (0.99

t/ha/year). For horticulture and plantation the soil loss rates were 1.47 and 5.39 t/ha/year respectively. For pasture, fallow and scrub the soil loss rates were 25.47, 28.39 and 35.76 t/ha/year respectively.

Parveen and Kumar (2012) studied the Integrated Approach of USLE and GIS for Soil Loss Risk Assessment in Upper South Koel Basin, Jharkhand. The rainfall erosivity R-factor of USLE was found as 546 MJ mm/ha/hr/year and the soil erodibility K-factor varied from 0.23 - 0.37. Slopes in the catchment varied between 0% and 42% having LS factor values ranging from 0 - 21. The C factor was computed from NDVI values derived from Landsat-TM data. The P value was computed from existing cropping patterns in the catchment. The annual soil loss estimated in the watershed using USLE was 12.2 t/ha/year.

Ahmad and Verma (2013) studied the USLE model and GIS, for soil loss estimation has been presented for the Tandula reservoir catchment area, Balod Tahsil of Durg district, Chhattisgarh. The result obtained from USLE model has been compared with existing model, Nayak and Khosla's method. It was resulted that the quantity of actual soil erosion calculated by USLE model comes out to be 490615 tonnes/year, the quantity of actual soil erosion calculated by Nayak model comes out to be 294588 tonnes/year and the quantity of actual soil erosion calculated by Khosla's method comes out to be 396286.479 tonnes/year. Study concluded that results obtained from USLE with GIS give better result as compared to other two methods.

Ghosh *et al.* (2013) estimated the assessment of soil loss of the Dhalai river basin, Tripura, India using USLE. The whole study area has been subdivided into 23 sub watersheds in order to identify the priority areas in terms of the intensity of soil erosion. Each sub-watershed has further been studied intensively in terms of rainfall, soil type, slope, land use/land cover and soil erosion to determine the dominant factor leading to higher erosion. The average annual predicted soil loss ranges between 11 and 836 t/ha/year. Low soil loss areas (<50 t/ha/year) have mostly been recorded under densely forested areas.

Amara *et al.* (2014) estimated the soil erosion using USLE and suggest possible intervention strategies to address soil loss in Singhanhalli-Bogur Microwatershed of Dharwad District in northern transition zone of Karnataka. The average annual soil loss was 27 t/ha/year. About 574 ha of the study area was under slight erosion, 118 ha under moderate erosion and 53 ha under severe erosion. The soil loss under different land uses ranged from 7 t/ha/year under forest to 40 t/ha/year under agriculture. The soil loss under plantation and open scrub land uses were 8 and 26 t/ha/year respectively. Major causes of soil erosion were cultivation without proper soil and water conservation measures in area not suitable for crops, denuded areas without vegetation, cultivated fallow on moderate slopes, degraded forests/pastures on steep slopes and poorly managed forest cover. Appropriate soil conservation and land management techniques for the different soil erosion classes were suggested.

Rasool *et al.* (2014) studied USLE parameters using RS and GIS in Sallar Wullarhama watershed, Jammu and Kashmir. The average rainfall erositivity factor (R) was calculated by using equation for the determination of R-value. The soil erodibility factor (K) values in the watershed ranges from 0.19 - 0.42, based on the soil texture class. For this study the (LS) factors were calculated after the generation of Digital Elevation Model (DEM) for the study area from the topographical sheet. The LS values of the study area ranges in between 0.5 - 5.5. The C-value of the study area ranges from 0.024 to 0.58 and P values ranges from 0.69-0.97. The average soil loss predictions range between 0.075565- 59.328 kg/m^2/yr.

Devatha *et al*. (2015) estimated the annual soil loss using USLE model for Kulhan watershed of Shivnath basin, sub-basin of Mahanadi basin, Chhattisgarh using RS and GIS techniques. It was found the highest value of estimated soil erosion potential was 556 t/ha/year and average annual soil erosion for study area was 0.1783 t/ha/year. And also it was observed that the soil erosion for Kulhan watershed was very less (0.1783 t/ha/year) because slope of the study area was gentle undulating about 10.49% and most of the area (78%) is occupied by agricultural land. It was found that 83.97% of total area was under slight erosion risk class and only 0.45% of total area under very high severe class.

Wolka *et al*. (2015) studied that soil erosion risk assessment in the Chaleleka wetland watershed, Ethopia. Results showed that 13.6 percent of the study area has a soil loss value less than 10 t/ha/year with the remaining area experiencing a higher soil loss. Moderate soil loss (10–20 t/ha/year) was observed in 15.5 percent of the watershed, covering the sub-watersheds in Upper Wesha, upper Hallo, and lower Lango. The soil loss severity class of high to very high (20–45 t/ha/year) occurs in 17.3 per cent of the total study area. Study concluded that significantly large area of the Cheleleka wetland watershed has non-tolerable soil erosion that threatens annual crop production, land productivity, and hydrological functioning of the area.

2.3 Estimation of tolerable soil loss and relationship between loss of yield and loss of topsoil

Wen and Easter (1987) studied the soil erosion and loss in crop productivity in Minnesota. Two regression models were used to estimate functional relationships between crop yields and soil characteristics for corn, soybeans, and wheat in south eastern Minnesota.

The relationships between topsoil depth and yield were found to be nonlinear for all three crops. The high level of significance of soil depth (SD) in explaining yield differences indicates that subsoil characteristics were important in determining corn and soybean yields. The analysis of conservation practice shows that strip cropping does not become profitable until SD drops to between 50 cm and 11 cm depending on crop prices and discount rates. Generally for deep topsoils, productivity losses from soil erosion are minor and adoption of conservation practices is not profitable for most farmers. Conservation practices only become profitable when the topsoil becomes relatively shallow.

Al-Kaisi (2001) studied the effect of soil erosion on crop productivity, particularly on yield. The main objective of the study was to determine the effects of slope and erosion and their interaction with other variables such as moisture, fertilizer rates and slope on crop productivity. As the A horizon thickness increased from 1.5 inches (midrange for the severely eroded soils) to 5 inches (midrange for moderately eroded soils), the estimated corn yield increase was 13 bushels per acre. The change in yield between soil A horizon, 5 inches thick, and soil A horizon, 12.5 inches thick (midrange for the slightly eroded soils), was 8.9 bushels per acre. In general the result show that corn yield was much greater for loess-derived soils compared with till-derived soils.

Bakker *et al.* (2003) studied the crop productivity-erosion relationship analysis based on experimental work. This study was conducted to examine whether general patterns emerge when the results of experimental studies on soil loss are combined and compared. Results from a number of studies that relate crop productivity to erosion were collected and quantified. The comparative-plot method showed an average reduction in crop productivity of 4.3% per 10 cm of soil loss, whereas the reduction averaged 10.9% for studies based on the transect method and 26.6% for desurfacing experiments. It is assumed that the desurfacing and transect methods overestimate the effect of soil erosion because (a) desurfacing experiments result in much stronger changes in soil properties than soil erosion that takes place gradually, and (b) transect methods often ‘‘include’’ effects of other processes that are related to topography. If this assumption was correct, then yield reductions of approximately 4% per 10 cm of soil loss should be considered realistic.

Bhattacharyya *et al*. (2007) studied that soil loss and crop productivity model in humid subtropical region in Tripura. The study described the relation between the topsoil loss due to erosion and the level of productivity. Also study estimated the tolerable soil loss and also demonstrated how topsoil loss can be converted into productivity loss to estimate soil conservation need. The study showed that annual soil loss has been estimated nearly 15 million tonnes every year in Tripura. And also resulted that conservation need (P factor) was 0.37.

Brhane and Mekonen (2009) estimated the soil loss using USLE at Medego watershed, Ethiopia. This study was conducted after massive SWC practices have been implemented in the past 15-year in the study watershed. Primary data and secondary data were collected to estimate soil loss by USLE. Study resulted that, the lowest soil loss was estimated on flat plains (< 2% slope) about 1.59 t/ha/year, which was less than the minimum tolerable soil loss (2 t/ha/year). Also the highest soil loss was from steep slopes (30-50%) which was 35.43 t/ha/year, about twice the maximum tolerable soil loss (18 t/ha/year). The average soil loss rate was 9.63 t/ha/year about half of the maximum tolerable soil loss.

Liu *et al.* (2010) studied the soil degradation in Northeast China. This paper was related to the importance of Northeast China's grain production to China, and describe the changes of sown acreage and grain production in past decades. The result showed that the moderately and severely water-eroded area accounted for 31.4% and 7.9% of the total, and annual declining rate was 1.8%. Erosion rate was 1.24–2.41 mm/year, and soil loss in 1°, 5° and 15° sloping farmlands were 3 t/ha/year, 78 t/ha/year and 220.5 t/ha/year, respectively. The resulted average annual declining rate of soil organic matter was 0.5%. Proper adoption of crop rotation can increase or maintain the quantity and quality of soil organic matter, and improve soil chemical and physical properties.

Larney and Janzen (2012) studied on what amount of topsoil which maintaining the crop yield and ascertain the effects of simulated erosion on soil productivity and methods for its amendment. The study showed that average grain yield reductions during the first 16 years were 10.0% for 5 cm, 19.5% for 10 cm, 29.0% for 15 cm, and 38.5% for 20 cm of topsoil removal and also a one-time application of livestock manure at the outset of the experiment was able to compensate for topsoil loss, especially in the early years of the study. The study reinforces the need to prevent soil erosion and indicates that application of livestock manure is an option for restoring soil productivity in the short term.

Kumar and Pani (2013) studied the effects of soil erosion on agricultural productivity in semi-arid regions in river Chambal forms the southern boundary of Badpura block and further flow form Chakarnagar block of district Etawah, Uttar Pradesh. In the present study Landsat satellite images for the years of 1977, 1990 and 2000 have been used to identify the change in degraded land in the region. Evidences suggest that the rate of encroachment of arable land was high and was equal to spreading rate of degraded land. The data obtained by field survey reveal that productivity of crop land was negatively correlated with share of degraded land to gross cropped area. The productivity of agriculture, measured through gross value of output per area, was comparatively high in villages having fewer shares of degraded land and vice-versa. Simple linear regression model explains high variation of productivity by high share of degraded land (above 50 per cent of gross cropped area). It was concluded that the region was severely affected by ravine and gully erosion and degraded land was expanding at an alarming rate. The result concluded that there was a need for micro-ecological management to stop the degradation before its impacts become catastrophic.

2.4 Estimation of productivity and tolerable soil loss

Kassam *et al.* (1991) studied the agro-ecological land resources assessment for agriculture development planning in Kenya. The study estimate the soil loss reduction needed for estimation of conservation practice factor (P). Calculated soil loss reduction was 66 t/ha (i.e. 146-80) and the total soil loss over 6 years of the crop cycle was 130 t/ha, which has to be reduced by 66 t/ ha to 64 t/ha. The result concluded that the P factor needed to achieve this was 0.49.

Lakaria *et al.* (2008) estimated the soil loss tolerance values for different physiographic regions of Central India. In India, a single soil loss tolerance (T) value of 11.2 Mg/ha was default used for formulating land restoration strategies for all soil types, climates and vegetation covers. Based on overall assessment, each soil mapping unit was categorized into soil groups I, II or III. A general guideline of USDA – Natural Resource Conservation Service (USDA-NRCS) was followed to calculate soil loss tolerance for each soil group using effective soil depth. Adjusted 'T' values for Central India ranged from 2.5 to 12.5 Mg/ ha compared with a default value of 11.2 Mg/ha. The study concluded that use of these values for soil mapping units will improve conservation planning and assist with planning the development of sustainable agriculture.

Mandal and Sharda (2011) studied the assessment of permissible soil loss in India. The analysis has indicated that soil loss tolerance or T-value varies from 2.5 to 12.5 Mg /ha/year depending upon soil quality governing soil resistibility to erosion and depth at a particular location. About 57% area in the country has permissible soil loss of less than 10.0 Mg/ha/year, which needs to be treated with appropriate conservation measures. Highest priority needs to be accorded to about 7.5% area where the T-value was only 2.5 Mg/ha/year due to soil quality constraints. Case study evidences in different watersheds revealed that soil productivity can be maintained at sustainable levels by bringing the erosion rate within tolerance limit.

Avanzi *et al.* (2013) studied the spatial distribution of water erosion risk in a watershed with eucalyptus and Atlantic. This study predicted the average potential annual soil loss by USLE and GIS, and then compared with soil loss tolerance. Results showed that the average soil loss was 6.2 Mg/ha/year. Relative to soil loss tolerance, 83% of the area had an erosion rate lesser than the tolerable value. According to soil loss classes, 49% of the watershed had erosion less than 2.5 Mg/ha/year and about 8.7% of the watershed had erosion rates greater than 15 Mg/ha/year, thus requiring special attention for the improvement of sustainable management practices for such areas.

Sharda *et al.* (2013) studied the soil erosion risk using integrating the spatial data on potential erosion rates and soil loss tolerance limits for conservation planning in different states of India. The analysis revealed that about 50% of TGA of India, falling in five prioritized erosion risk classes, requires different intensity of conservation measures though about 91% area suffers from potential erosion rates varying from <5 to >40 t/ha/year . state wise analysis indicated that Andhra Pradesh, Maharashtra and Rajasthan share about 75 % of total area under priority class 1 (6.4 M ha) though they account for only 19.4% of the total area (36.2 M ha) under very severe potential erosion rate category (>40 t/ha/year). It was observed that about 75% of total geographical area TGA in states of Bihar, Gujrat, Haryana, Kerla and Punjab does not require any specific soil conservation measures as the potential erosion rates were well within the tolerance limits.

Lenka *et al*. (2014) studied the permissible soil loss limits for different physiographic regions of West Bengal. In this study, the maximum permissible soil loss rates (T values) were computed for 115 mapping units of WB. The results suggested a wide difference in the T values among the regions and mapping units, with values ranging from 2.5 to 12.5 Mg/ha/year. In the state as a whole, about 88% of the area has 'T' value of 12.5 Mg/ha/year. The relatively plain lands in the Indo-Gangetic plain, coastal and delta plain and the Bengal basin have a higher soil loss tolerance of about 4.0 Mg/ha/year than the hilly and undulating regions in the Eastern Himalaya and Eastern plateau regions. The information generated will serve as a useful guide for devising differential conservation and resource use plans on the basis of soil resource potential.

Ayalew (2015) studied the erosion-prone watersheds in the highlands of Ethiopia of Zingin watershed by using RS and GIS. Based on the analysis, the mean and total annual soil loss potential of the study watershed were 9.10 and 57750.15 tonnes/year, respectively. About 78.31% (4,969.63 ha) of the watershed was categorized none to slight class which under soil loss tolerance (SLT) values ranging from 5 to 11 tonnes/ha/year. The remaining

21.69% (1376.48 ha) of land was classified under moderate to high class about several times the maximum tolerable soil loss (11 tonnes/ha/year).

2.5 Critique of Reviews

From the above reviews it is found that land use/ land cover change detection was useful to prepared sustainable land use planning and management towards protection of extremely rich biodiversity.

Soil degradation has reached alarming proportions in many parts of the world, especially in tropics and subtropics. It also leads to decreased agricultural productivity. Hence, efficient management of natural resources viz. soil and water is the major challenge for agricultural scientists, planners and farmers to ensure food, water and environmental security for present future generations.

Ratnagiri district is the part of Konkan region of Maharashtra which having higher soil erosion through runoff, extreme weather conditions, hilly terrain and undulating topography. Due to soil erosion and runoff rich fertile topsoil erodes. Thus, estimation of soil loss is essential to plan soil and water conservation measures of Ratnagiri district.

Universal Soil Loss Equation (USLE) and use of Geographical Information System (GIS) and Remote Sensing (RS) helps to estimate soil loss. USLE was found useful in planning of soil and water conservation measures and watershed management techniques/programmes for different soil erosion classes in many parts of the world.

Soil and water conservation measures help to control soil loss. The study of relationship between topsoil loss and yield loss which is essential for estimation of tolerable soil loss (T-values). In few studies estimated values of tolerable soil loss was used to convert topsoil loss into productivity loss to estimate soil conservation needs.

Studies of relating soil and water conservation measures with tolerable soil loss are very few. In Konkan region of Maharashtra these kinds of studies are not available. So this study will help in estimation of tolerable soil loss and water conservation approaches use for conservation planning and assist the planning the development of sustainable agriculture. Soil productivity of Ratnagiri district can be maintained at sustainable levels by bringing erosion rate within tolerance limit, with proper planning.

III. MATERIALS AND METHODS

This chapter deals with the description of study area, data collected, procedure adopted to estimate parameters of Universal Soil Loss Equation (USLE) using Remote Sensing (RS) and Geographical Information System (GIS) for estimation of soil erosion and estimate the tolerable soil loss for Ratnagiri district.

3.1 Study Area

Ratnagiri is a coastal district of Maharashtra state, situated in the western coast of India. Ratnagiri district is located between $15^0 40'$ and 18°5' N latitude and $73^0 5'$ and $73^0 55'$ E longitude. The total geographical area of Ratnagiri district is 8,461 sq. km. It has north-south length of about 180km and average east-west extension of about 64km. Sahyadri hills surround it in the east beyond which there are Satara, Sangli and Kolhapur districts. Raigad district in the north, the Arabian Sea in the west and Sindhudurg district in the south. Average annual rainfall of Ratnagiri district is 3,591mm. The Ratnagiri district is divided into nine tehsils, namely Mandangad, Dapoli, Khed, Chiplun, Guhagar, Sangmeshwar, Ratnagiri, Lanja and Rajapur. Tehsil wise area covered under Ratnagiri district is shown in Table 3.1.

Table 3.1. Tehsil wise area of Ratnagiri District

Sr. No.	Name of tehsils	Area (km^2)	Latitude	Longitude
1	Chiplun	1119.953	17.5333	73.5167
2	Dapoli	910.4047	17.7528	73.1899
3	Sangameshwar	1268.457	17.1871	73.5521
4	Guhagar	694.9036	17.4901	73.2659
5	Khed	1025.82	17.7210	73.4103
6	Lanja	753.5026	16.8521	73.5490
7	Mandangad	446.6764	17.9879	73.2557
8	Rajapur	1264.76	16.6700	73.5200
9	Ratnagiri	976.976	16.9902	73.3120

	Total	**8461.453**	**16.992**	**73.2923**

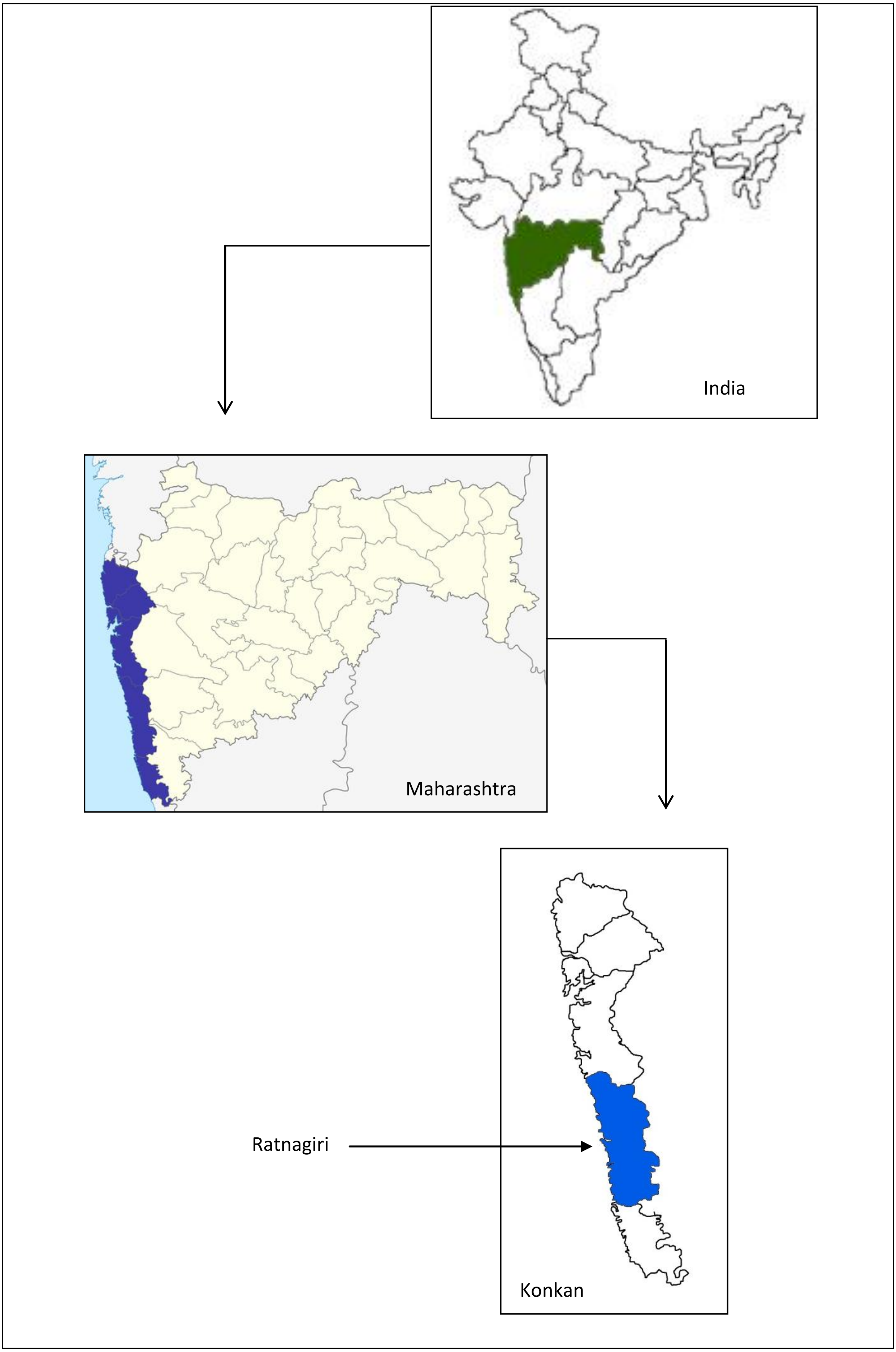
India
Maharashtra
Ratnagiri
Konkan

Fig. 3.1 Location map of study area

3.2 Data Collection and Pre-processing

The following section presents the data used to compute USLE factors for the Ratnagiri district.

1. Daily rainfall data from 1984 to 2011 of five stations in the Ratnagiri district were used to compute annual rainfall erosivity (R factor). Daily rainfall data of Hedavi, Karak and Poynar stations were collected from the Water Resource Department, Hydrology Project, Government of Maharashtra, Nasik and daily rainfall data of Dapoli and Wakawali stations were collected from Department of Agronomy Dr. B.S.K.K.V., Dapoli.
2. The different soil parameters such as sand, silt, clay and organic carbon were collected from M. Tech. thesis (Thawakar, 2014).
3. Digital elevation model (DEM) of the study area was prepared using SRTM data (http://.srtm.csi.cgiar.org.). A slope map was created from the DEM based on the slope map, slope length (L) and slope gradient(S) maps and finally a layer of LS factor was generated.
4. Satellite images were downloaded from LANDSAT imageries (ftp.glcf.umd.edu) used for preparation of land use land cover map. Crop cover data of Ratnagiri district was collected from the District Superintending Agriculture Office, Ratnagiri, Maharashtra to obtain the crop cover management factor (C).
5. The values of bulk density of different location for all tehsils of Ratnagiri district were adopted from M.Sc. Thesis (Joshi, 2012 and Sonawane, 2013).

3.3 Soil Erosion-USLE

The Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith, 1978 was used for estimation of soil loss. The USLE was proposed for estimating sheet and rill erosion sediments losses from cultivated fields. The USLE and its predecessors were meant as field-level conservation planning rather than research tools, and were therefore structured to be 'user friendly' for USDA programmes in the Soil Conservation Service (SCS) and designed for adapting erosion-control practices to the needs of specific fields and farms. This empirical equation, based on a large mass of field data, computes sheet and rill erosion as annual average soil loss (t/ha/yr) using the values representing the four major types of factors affecting erosion. These factors are climatic, soil, topographic, land use and management. The equation given by Wischmeier & Smith (1978) is,

$$A = R*K*L*S*C*P \qquad \text{..... (3.1)}$$

Where, A is computed soil loss (t/ha/yr), R is the rainfall erosivity factor (MJ-mm/ha-hr-yr), K is the soil erodibility factor (t-ha-hr/ha-MJ-mm), L is the slope length factor (m), S is the slope steepness factor, C is the crop cover management factor, and P the conservation practice factor. It is very simple and powerful tool for predicting the average annual soil loss in specific situations. The associated factors of the equation can be predicted by easily available meteorological and soils data.

The USLE (Wischmeier & Smith, 1978) became very widely used, both within the US and internationally. Perhaps its most common use was as one of the primary tools of the USDA Soil Conservation Service for conservation planning on agricultural lands. As use of the USLE expanded and it was applied in other situations, like disturbed forest lands (Dissmeyer & Foster, 1981, 1984), limitations of the technology became apparent. At the same time, continuing soil erosion research on both natural plots and under simulated rainfall led to improve understanding of the physical processes involved in hillslope sheet and rill erosion.

The use of USLE model requires that the user should be aware of model limitations. It is an equation that predicts average annual soil loss by assessing the sheet and rill erosion but not used for predicting the gully erosion. Also, it does not compute sediment deposition.

3.4 Development of USLE parameters

3.4.1 Rainfall Erosivity Factor (R)

Rainfall erosivity refers to the ability of rainfall to erode the soil particles from an unprotected field. The concept of rainfall erosivity was introduced by Wischmeier and Smith (1959) to encapsulate the climatic influence on soil erosion in such a way that, when other variables are held constant, rate of soil loss is directly proportional to the level of rainfall erosivity. Rainfall erosivity is the rainfall energy to detach the soil particles, because energy is required to break the soil aggregated into finer, so that they can be splashed out and subsequently moved off through runoff.

The numerical value of R in the soil loss equation must quantify the raindrop impact effect and must also provide the relative information on the amount and rate of runoff likely to be associated with the rain. The research data indicated that when factors other than rainfall are held constant, soil losses from cultivated fields are directly proportional to a rainstorm parameter identified as the EI. For an individual storm, EI_{30} is the product of the total kinetic energy and maximum 30 minute intensity of the storm. The kinetic energy of a rainstorm depends on the size and terminal velocity of the raindrops, which are related to intensity. Hence, the energy of a rainstorm is a function of the amount and intensity of rainfall. Both number and size of raindrops increase with rain intensity and velocity of rainfall.

3.4.1.1 Erosivity index determination

Computation of erosivity index comprises following steps:

3.4.1.1.1 Method of computing rainfall intensity (I)

Rainfall intensity is important for computation of kinetic energy of the individual storm. Rainfall intensity is the ratio of rainfall depth (mm) of individual storm to the time of precipitation of the same storm (hr). For the rainfall less than 15 minute, records cannot properly examined for analysis purpose. These records have negligible effects on erosivity index estimation, so they are not considered for the purpose of analysis.

3.4.1.1.2 Method for computing 30-min maximum rainfall intensity from hyetograph

Maximum rainfall intensity (I_{30}) represents the maximum rainfall occurred in any 30-minute time period during the 24 hours converted into intensity (mm/hr). The depth of maximum rainfall was found out. Rainfall depth was multiplied by two to convert it into rainfall intensity.

3.4.1.1.3 Method for determination of kinetic energy (e)

Kinetic energy of individual storm was calculated by equation given by Foster *et al.* (1981). The equation is given as,

$$e = (0.119 + 0.0873 \log_{10} I) \quad I < 76 \text{ mm/hr} \quad \text{..... (3.2)}$$

$$e = 0.283 \quad I > 76 \text{ mm/hr} \quad \text{..... (3.3)}$$

3.4.1.1.4 Total kinetic energy (E)

Total kinetic energy of individual storm was calculated by multiplying the rainfall depth to kinetic energy of that storm.

$$e = (0.119 + 0.0873 \log_{10} I) \times \text{Depth} \quad \text{..... (3.4)}$$

Where, I = Rainfall intensity (mm/hr), Rainfall depth in mm.

3.4.1.1.5 Rainfall erosivity factor (R)

The erosivity factor R is the sum of individual storm erosivity value (EI_{30}) of storm over a time period. Rainfall erosivity factor is the potential ability of rain to cause erosion and is computed by using following relationship,

$$R = E \times I_{30} \qquad \text{..... (3.5)}$$

Where, R = Rainfall erosivity factor (MJ-mm/ha-hr-yr)

3.4.1.2 Computation of R factor using daily data

Energy of rainfall event is a function of the amount of rain and its intensities for the event. The EI_{30} was closely related to the intensity of every storm and also with the depth of rainfall occurred in that storm. But it was not related to the amount of rainfall occurred in whole day i.e. daily precipitation, since there were many non-erosive storms also occurred in the 24 hours. Several research scientist from this field did the estimation of EI_{30} value of the day from daily precipitation, these relation were tried out for the particular region where the data of intensity was not available.

In present study there are five rain gauge stations as Hedvi, Karak, Poynar, Dapoli and Wakawali. Erosivity index of Wakawali station was calculated by EI_{30} method (Yadav and Mhatre, 2005). Rainfall intensity data was not available for Hedvi, Karak, Poynar and Dapoli raingague stations. Daily rainfall data of Hedvi, Karak, Poynar and Dapoli stations for 28 years (1984-2011) was available. For these stations there is need to develop the regression equation to calculate the erosivity index. For this purpose the daily precipitation and EI_{30} data of Wakawali station were used for regression analysis (Yadav and Mhatre, 2005) and regression equation was obtained for computing the daily erosivity index from trade line of graph. The following equation implies the correlation between daily Erosivity Index and daily rainfall.

$$Y = 0.3339x^{1.50} \qquad \text{..... (3.6)}$$

Where, Y is daily erosivity index and x is daily precipitation.

The equation found was power in nature and the coefficient of determination obtained was 0.7624. Hence, equation 3.6 has been used in the present study to compute R factor values for five stations using daily rainfall data for 28 years, where intensity data was not available.

3.4.1.3 Creation of rainfall erosivity (R) map

A point map of five rainfall stations was prepared in ArcGIS 10.2 using X and Y coordinates obtained from Google Earth map. Then Thiessen polygon map was created by Nearest Point method. Daily R values for the years 1984 to 2011 were computed for five stations of Ratnagiri district (Eqn. 3.5). Annual and average erosivity values obtained from 28 year data for all five stations were obtained by summation of daily erosivity values. These values were assigned to respective polygons in thiessen polygon to get Rainfall Erosivity (R) map.

3.4.2 Soil Erodibility Factor (K)

The meaning of the term "soil erodibility" is distinctly different from that the term "soil erosion". The rate of soil erosion, A, in the soil loss equation, may be influenced more by land slope, rainstorm characteristics, cover and management than by inherent properties of the soil. However, some soils erode more readily than others even when all other factors are the same. This difference caused by properties of the soil itself, is referred to as the soil erodibility.

Soil erodibility is the vulnerability or susceptibility of the soil to get eroded. Erodibility is the function of physical characteristics of soil and land management practices, used. Conceptually, the soil erodibility reflects the view of getting soil particles removed at different rates depending on several physical characteristics, such as texture, organic matter, structure and bulk density of the soil. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot. Soil erodibility relates the various soil properties, by virtue of which a particular soil becomes susceptible to get erode, either by water or wind. Soil erosion is a process of detachment and transportation of soil materials from its original place by the action of various erosive forces. In general, the soil properties such as the soil permeability, infiltration rate, soil texture, size and stability of soil structure, organic content and soil depth, affect the soil loss in large extent. The soil erodibility factor (K) is expressed as tonnes of soil loss per hectare per unit rainfall erosivity index from a field of 9 % slope and 22 meters as field length.

3.4.2.1 Computation of soil erodibility (K)

The K factor was computed for each soil type of Ratnagiri district with the help of data obtained from soil analysis regarding soil texture, structure, permeability and organic matter content. As direct determination of the K factor requires long-term measurements of soil loss, which is costly and time consuming. An algebraic approximation of the nomograph that includes soil parameters such as texture, structure, permeability and organic matter content is proposed by Wischmeier and Smith (1978) and Renard *et al.* (1997).

$$K = \{[2.1 * 10^{-4} M^{1.14} (12-a) + 3.25 (b-2) + 2.5 (c-3)]/100\} * 0.1317 \quad ..... (3.7)$$

Where,

K = soil erodibility factor (t-ha-hr/ha-MJ-mm),

M = (% silt + 0.7 * % sand) * (100 - % clay),

a = organic matter content,

b = structure of the soil,

c = permeability of the soil

In the present study the different soil parameters such as sand, silt, clay and organic carbon were collected from M. Tech. thesis (Thawakar, 2014; Estimation of erodibility of selected locations in Konkan region) Dr. B.S.K.K.V., Dapoli. Based on these data parameters required for erodibility estimation (Equation 3.7) were determined by using various relationships among the soil characteristics. Organic matter content has been calculated from organic carbon of soil (Equation 3.4). Permeability code (Table 3.3) has been judged from permeability classes based on hydraulic conductivity (Table 3.2) obtained by using "Soil-Plant-Air-Water" (SPAW) model.

The erodibility values were computed for total 45 villages from nine tehsils of Ratnagiri district. 9 tehsils of Ratnagiri district having 5 villages for each tehsil. Erodibility was calculated as per the Wischmeier and Smith (1978) and Renard *et al.* (1997) formula (Eqn. 3.7).

Table 3.2. Permeability classes based on hydraulic conductivity of soil

Permeability classes	**Hydraulic conductivity(cm/hr)**
Extremely slow	< 0.0025
Very slow	0.0025-0.025
Slow	0.025-0.25
Moderate	0.25-2.5
Rapid	2.5-25.0
Very rapid	> 25

(Smith and Browning, 1946)

Table 3.3. Permeability code for different types of soil

Code	Description	Rate (mm/h)
1	Rapid	>130
2	Moderate to rapid	60-130
3	Moderate	20-60
4	Slow to moderate	5-20
5	Slow	1-5
6	Very slow	<1

3.4.2.2 Soil structure

The arrangement and organization of primary and secondary particles in a soil mass is known as soil structure. Soil structure controls the amount of water and air present in soil. Soil particles may be present either as single individual grains or as aggregate i.e. group of particles bound together into granules or compound particles. These granules or compound particles are known as secondary particles. A majority of particles in a sandy or silty soil are present as single individual grains while in clayey soil they are present in granulated condition. The individual particles are usually solid, while the aggregates are not solid but they possess a porous or spongy character. Most soils are mixture of single grain and compound particle. There are four principal forms of soil structure like plate-like (platy), prism-like, block like and spheroidal (sphere like).

So first textural classes of soil were determined by using SPAW model. Based on these textural descriptions, structural codes (Table 3.6) were obtained from different particle size proposed by NBSS and LUP, 1988 (Table 3.4 and Table 3.5). Particle size distribution of sand, silt, clay was taken into account for deciding textural class. Accordingly structural codes were identified for each type of soils (Table 3.6). These structural codes were used in erodibility equations for all 45 villages of Ratnagiri district.

Table 3.4. Textural class proposed by USDA

Soil Separate	Diameter range (mm)
Coarse sand	2.00 – 0.20

Fine sand	0.20 – 0.02
Silt	0.02 – 0.002
Clay	Below 0.002

Table 3.5. Structural Classes of different soil

Class	**Range**
Very fine	Less than 1 mm thickness
Fine	1 – 2 mm thickness
Medium	2 – 5 mm thickness
Coarse	5 – 10 mm thickness
Very Coarse	More than 10 mm thickness

(Source: NBSS and LUP, 1988)

Table 3.6. Structure code for different types of soil

Code	**Structure**	**Size (mm)**
1	Very fine granular	<1
2	Fine granular	1 – 2
3	Moderate or Coarse granular	2 – 10
4	Blocky, platy or massive	>10

(Source: NBSS and LUP, 1988)

3.4.2.3 Organic matter

Organic matter has a variable influence on soil and affects both its chemical and physical properties. The effect of organic matter on physical properties relates largely to its abilities to bind soil particles together. So the organic constituents of soil are important because of their influence on aggregate stability. Soil with less than 3.5% organic carbon can be considered erodible. In present study organic carbon data was available. So organic matter of soil was determined by following equation (Hesse, 1971), for 45 villages of Ratnagiri district.

$$\text{Organic matter} = \text{Organic carbon} * 1.724 \qquad \text{..... (3.8)}$$

3.4.2.4 Creation of soil erodibility (K) map

Soil parameters such as sand, silt, clay and organic carbon were collected (M. Tech. thesis, Thawakar, 2014). Based on these data soil parameters required for estimation of erodibility were determined using above relationships and models. K factor values for 45 villages of the Ratnagiri district were calculated by using Eqn. 3.7. Soil erodibility factor (K) value was assigned to each village of Ratnagiri district in ArcGIS 10.2. The Inverse Distance Weighted (IDW) Technique was used for interpolation to get Soil Erodibility (K) map.

3.4.3 Topographic Factor (LS)

Topographic factor (LS) is the expected ratio of soil loss per unit area from a field to that from a 22.13 m length of uniform 9% slope under otherwise identical conditions (Wischmeier and Smith, 1965). The LS factor represents the erosive potential of a particular soil with specified slope length and slope steepness. This factor basically affects the transportation of the detached particles due to the surface flow of rainwater, either that is the overland flow or surface runoff. And accordingly affects the value of soil erosion due to any given rainfall. The capability of runoff/overland flow to detach and transport the soil materials gets increased rapidly with increase in flow velocity. On steep ground surface the runoff gets increased because of increase in runoff rate. Thus, for a given direction of rain, the proportion of rain actually intercepted on the ground will vary with aspect and/or slope. So hill slope gradient (S) and length (L) factors are combined into a topographic factor (LS) while estimating soil erosion.

3.4.3.1 Computation of topographic factor (LS)

3.4.3.1.1 Slope length factor

Slope length is the horizontal distance from the point of origin of overland flow to the point where either the slope gradient gets decrease enough to start deposition or the overland flow gets concentrate in a defined channel. In principle, longer the slope length the more runoff will be there; gathering the speed and gaining its own energy and thus resulting into rill erosion and formation of gully network.

The relationship between the slope steepness in percentages (Sp) and slope length in meters (L) were used to generate slope length map. It is given by,

$$L= 0.4 * Sp + 40 \qquad ..... (3.9)$$

Where,

L = Slope length in meter

Sp = Slope steepness in percentage

By applying equation 3.9 the resultant map was prepared in ArcGIS10.2 for slope length.

3.4.3.1.2 Topographic factor (LS)

Although L and S factors were determined separately, the procedure has been further simplified by combining the L and S factors together and considering the two as a single topographic factor (LS) (Wischmeier and Smith, 1965). Combined LS factor layer was generated as,

I**.** For slopes up to 21 %, the equation modified by Wischmeier and Smith (1978) was used which is,

$$LS1= (L / 22.13) *(65.41 \sin^2\theta + 4.56 \sin \theta + 0.065) \qquad ..... (3.10)$$

Where, LS1 is the slope length and gradient factor and θ is angle of the slope.

II**.** For slope steepness of 21 % or more, the equation used, which is given by

$$LS2= (L / 22.13)^{0.7} * (6.432 * \sin (\theta^{0.79}) *\cos (\theta)) \qquad ..... (3.11)$$

Where, LS2 is the slope length and gradient factor, θ is angle of the slope and L is slope length in meter.

3.4.3.2 Creation of topographic factor (LS) map

Digital elevation model (DEM) of the Ratnagiri district was prepared using SRTM data. Shuttle Radar Topography Mission (SRTM) was downloaded from http://.srtm.csi.cgiar.org. A slope map in percent and slope map in degree was prepared from the DEM in ArcGIS 10.2. Based on these slope maps, slope length (L) and slope gradient(S) maps and finally a layer of LS factor were generated for Ratnagiri district.

3.4.4 Crop Management Factor (C)

Crop management factor is the ratio of soil loss from a cropped land under specific condition to soil loss from a continuous fallow land, provided that soil type, slope and rainfall conditions are identical. The crop management factor (C) reflects the combined effect of crop cover, crop sequence, productivity level and entire length of growing season, tillage practices, residue management and the expected time distribution of erosive rainstorm with respect to seeding and harvesting date. The crop and cropping practices affect the soil erosion in several ways such as kind of crop, quality of cover, root growth. Since these features differ significantly within the period from planting to the crop harvesting, therefore, the soil loss gets affected. Similarly, the variation in rainfall distribution within the year also affects the crop management factor, which affects the soil loss accordingly. The crop management factor (C) of USLE reflects the reduction in soil loss on growing of crops and application of proper management practices in view of development of good ground cover, as compared to the land without any vegetative cover. The reduction in soil loss due to vegetative cover depends on the types of crop grown, cropping system, tillage practices and residue management practices followed. The crop management practices affect the erosion for the duration up to which they are capable to keep the surface rough or covered with crop residues or vegetation. The land use/land cover map was served as a guiding tool in the allocation of C factor for different land use classes.

3.4.4.1 Computation of crop management factor (C)

Depending upon the available land use-land cover data of study area, the C factor values were assigned to the Ratnagiri district according to literature. Table 3.7 shows C values used in the present study. Crop management factor is the expected ratio of soil loss from a cropped land under specific condition to soil loss from clean tilled fallow on identical soil and slope under the same rainfall conditions. The type of the land cover, the manner in which it is managed and the changes that have taken place over time, which formed the basic premise for evaluating soil loss from a watershed. LANDSAT imageries (ftp.glcf.umd.edu, Path No. 147, Row No. 48 and 49, February 2004) were used for preparation of land use land cover map. Crop cover data of Ratnagiri district was collected from the District Superintending Agriculture Office, Ratnagiri, Maharashtra to obtain the crop cover management factor (C). The C factor values were the representative values for allocating the USLE land cover and management factors corresponding to each crop/vegetation condition.

Table 3.7. Land use/land cover and C value

Land use/land cover	C value
Forest (Rasool *et al*. 2014)	0.04
Barren land (Rasool *et al*. 2014)	0.034
Built-up (Rasool *et al*. 2014)	0.024
Horticultural crops (Pal and Samanta, 2011)	0.1
Oilseeds (Panagos *et al*. 2015)	0.28
Rice (Panagos *et al*. 2015)	0.15

3.4.4.2 Creation of crop management factor (C) map

LANDSAT data used to find out the various land use classes. Weighed value of C based on cropping pattern was calculated for particular classes of the Ratnagiri district obtained from existing literature. The weighted C factor values were calculated for different classes. Then C factor values were assigned to respective grid code in study area in ArcGIS 10.2 to get C factor map.

3.4.5 Conservation Practice Factor (P)

It may be defined as the ratio of soil loss under a given conservation practice to the soil loss from up and down the slope. In general, whenever sloping soil is to be cultivated and exposed to erosive rains, the protection offered by sod or close-growing crops in the system needs to be supported by practices that will slow the runoff water and thus reduce the amount of soil it can carry.

3.4.5.1 Creation of conservation practice factor (P) map

P factor was assigned as 1 for the Ratnagiri district as it was untreated in ArcGIS 10.2 to get P factor map.

3.5 USLE Modeling

The USLE model was developed as a tool to assist soil conservators in watershed management planning. A conservator used the USLE to estimate soil loss on specific slopes in specific fields. In situation of the estimated soil loss exceeding the acceptable limits, the USLE provides guidelines to the conservator and farmer in choosing practices that would control erosion adequately while meeting the needs and expectations of a farmer.

3.5.1 Estimation of Average Annual Soil Loss Using USLE

The universal soil loss equation (USLE) developed by Wischmeier and Smith (1978) was used in this study for estimating soil loss. This model has been widely accepted and utilized in most the countries. Hence, this model was chosen for this study. The USLE equation is as follows,

$$A = R * K * L * S * C * P \quad \text{..... (3.12)}$$

Where,

A = soil loss in tons/ha/year

R = rainfall erosion factor (MJ-mm/ha-hr-yr)

K = soil erodibility factor (t-ha-h / ha-MJ-mm)

L = slope length factor (m)

S = slope gradient factor

C = crop management factor

P = conservation practice factor

Equation 3.12 computes soil loss due to sheet and rill erosion, which can be controlled by adopting erosion control measures. It is also possible to estimate the effectiveness of various conservation measures.

All the layers viz. R, K, LS, C and P were generated in ArcGIS 10.2 and were overlaid to obtained the product, which gives annual soil loss (A) for the Ratnagiri district. Annual soil loss was calculated for the Ratnagiri district.

3.6 Estimation of tolerable soil loss

Both concepts of soil loss tolerance and USLE as practiced in United States since 1940s have gradually evolved during the process of soil and water conservation (Wishmeier and Smith, 1978). The earlier concept of T value focused on physical factors, such as soil productivity maintenance etc., both physical and economic factors such as, cost of replacing the lost nutrients during soil erosion. Smith (1941) defined the soil loss (T-value) value as the amount of soil that could be lost without a decline of fertility, thereby maintaining crop productivity indefinitely. Later Wishmeier and Smith (1978) defined it as "the maximum level of soil erosion that will permit a high level of crop productivity to be obtained economically and indefinitely".

In the present model, the estimation was based on short-term losses in crop production due to loss of fertile topsoil, and long term losses in land productivity due to reduction of overall depth of the soil profile. The soil loss reduces the water holding capacity, nutrient-holding capacity and finally the anchorage is affected, which decrease the crop yield. The model was provided to assess tolerable soil loss keeping in view its likely impact on crop yield and future availability of cultivable land. The soil erosion and productivity model was linked to crop productivity, which provides assessments for the estimation of tolerable soil loss.

3.6.1 T value and its influencing factors

The T value was first put forward in the United States in 1956 and few influencing factors (USDA, 1956) of T value for a particular soil included:

1. The rate of soil formation from parent material;
2. The rate of topsoil formation from subsoil;
3. Reduction of crop yield by erosion;
4. Soil depth;
5. Loss of plant nutrients by erosion;
6. The availability of feasible, economic, culturally and socially acceptable, as well as sustainable soil conservation practices.

The loss of crop yield due to loss of top soil may be compensated by the formation of new soil through pedogenesis (Pedogenesis is the process of soil formation as regulated by the effects of place, environment, and history and also termed soil development, soil evolution, soil formation, and soil genesis). It should be interested to observe that the process of soil formation and soil erosion occur simultaneously in nature. To calculate the net loss of topsoil it will be necessary to take into account the amount of soil regenerated, difference in the rate of soil formation under different types of climatic conditions. Therefore, the rate of topsoil formation was considered as a factor in the model in assessing loss of productivity and tolerable soil losses.

Topsoil formation at the rate of 1 mm/year was equivalent to an annual addition of 13.3 tonnes/ha, taking into account the weight of a hectare furrow slice (15 cm depth) soil as 2.2×10^6 kg (Bhattacharya *et al*., 2007). Since, Ratnagiri represents a tropical wet climate; the soil formation rate of 2.0 mm should be equivalent to an annual addition of $(2.2 \times 10^6/150) \times 2.0 = 29$ tonnes/ha soil.

3.6.2 T value and soil productivity

Soil erosion removes the most fertile topsoil, upon which the crops rely. Since soil productivity is determined by the conditions of soil, it will affected by erosion. Firstly, crop yields are heavily dependent on soil moisture (Hall *et al.*, 1985) because all plants require sufficient water for growth. Soil erosion causes soil loss and reduces depth of topsoil, which reduces the soil water storage capacity and thus crop yields. Secondly, soil nutrients are one determiner of crop production. The loss of nutrients in topsoil caused by erosion is a direct reason for the decline of soil productivity.

In present study the relationship between topsoil loss and yield loss was estimated on the basis of available data, soil have been classified in terms of their susceptibility to productivity loss of topsoil. These ranking of susceptibility of the soils were related to actual yield losses, and by input levels which were calculated by set of linear equations (Table 3.8).

There were two relations used to estimate the tolerable soil loss

1. Relation between crop yield and loss of topsoil.
2. Proportion of land that can be allow to make the soil shallower at least by one soil depth class over a specified time period.

Table 3.8. Relationship between topsoil loss and yield loss

Soil susceptibility	Input level	Yield loss, y (%)
Least susceptible	Low	y = 1.0 x
	Intermediate	y = 0.6 x
	High	y = 0.2 x
Intermediate susceptible	Low	y = 2.0 x
	Intermediate	y = 1.2 x
	High	y = 0.4 x
Most susceptible	Low	y = 7.0 x
	Intermediate	y = 5.0 x
	High	y = 3.0 x

(Bhattacharya *et al*., 2007)

In table 3.8, x = topsoil depth (cm). If x = 25 cm, then in least susceptible soils with low input, yield loss was 25 % as against 50 % and 175 % in case of intermediate and most susceptible soils with low inputs.

3.6.3 Relationship between loss of yield and loss of topsoil

The tolerable loss rate for a given soil unit and specified amount and time scale of yield reduction was calculated by following equation,

$$TL = \frac{((\frac{Ra}{Rm} * 100 * BD * D) + 3T)}{T} \quad \text{….. (3.13)}$$

Where,

TL = tolerable soil loss rate (t/ha/yr),

Ra = the acceptable yield reduction (%),

Rm = The yield reduction (%) at the given input level when the effective topsoil was lost,

BD = bulk density of soil (Mg/m^3),

D = depth of effective topsoil (cm),

In present study the tolerable loss rate (t/ha/yr) for nine tehsils of Ratnagiri district were calculated (Eqn. 3.13) over a specified number of years (e. g. 100 year).

3.6.4 Proportion of land that can be allow to make the soil shallower at least by one soil depth class over a specified time period.

The estimation of the effect of soil depth reduction is based on the assumption that there is no significant loss of productivity until the soil becomes so shallow that shortage of moisture becomes a limiting factor.

To calculate the soil losses, soil-depth reduction may be measured in terms of proportion of the soils in an area that was shallower than a given depth due to erosion. The rate of soil loss is related to the proportion of land whose soil has become shallower than a specified depth by the following equation,

$$P = \frac{SL*T}{BD*D} \quad \text{..... (3.14)}$$

Where,

P = proportion of land downgraded to at least the next depth class (%),

SL = soil loss (t/ha/yr),

T = Time (years),

BD = bulk density of the soil (Mg/m^3),

D = depth range of soil class (cm)

Thus, depending on the permissible limit of minimum 25 cm soil depth to allow crop production, the D values were vary with the different depth classes as 25 cm (50-25= 25 cm) for shallow (<25 cm) and moderately shallow (25-50 cm), 75 cm (100-25 = 75 cm) for moderately deep (50-100 cm), 125 cm (150-25 = 125 cm) for deep (100-150 cm) and 150 cm (175-25 = 150 taking soil depth as minimum 175 cm) for very deep soils (>150 cm) respectively. The values of bulk density of different location for all tehsils of Ratnagiri district were used as shown in Table 3.9. Thus, the tolerable loss rate (t/ha/yr) and proportion of land downgraded to at least the next depth class were calculated for nine tehsils of Ratnagiri district (Eqn. 3.13 and Eqn. 3.14).

Table 3.9. Bulk density of each tehsils of Ratnagiri district

Tehsil Name	Bulk density (Mg/m^3)
Mandangad	1.26
Guhagar	1.22
Chiplun	1.26
Sangameshwar	1.22
Rajapur	1.25
Khed	1.23
Ratnagiri	1.23
Lanja	1.23
Dapoli	1.23

(Joshi, 2012 and Sonawane, 2013)

3.7 Application of soil erosion and productivity model

3.7.1 Total soil loss by erosion

Soil erosion is a growing problem especially in areas of agricultural activity where soil erosion not only leads to decreased agricultural productivity but also reduces water availability. Soil degradation has reached alarming proportions in many parts of the world, especially in the tropics and sub-tropics. Therefore, seeking immediate attention for soil conservation.

The realistic soil erosion datasets thus appear to be more useful for soil conservation measures. In India, totally six classes of soil erosion were identified (Table 3.10) as slight, moderate, moderately severe, severe and extremely severe. Taking the median value of the soil erosion range, the total soil lost under different erosion classes was estimated. This will help in taking up the soil conservation measures to control the soil erosion from highly erosion prone areas of study area.

Table 3.10. Area under different classes of soil erosion in India

Class	Soil loss (t/ha/yr)
Slight	<5
Moderate	5-10
Moderately severe	10-20
Severe	20-40
Very severe	40-80
Extremely severe	>80

(Singh *et al.*, 1992)

3.7.2 Estimation of conservation practice factor P

In this model, potential erosion losses for each desired class of land use may be evaluated assuming that there was no specific soil conservation measures were applied, which indicated that the conservation practice factor (P) is one. The soil conservation measures are required to control soil erosion and runoff after estimation of soil loss from the study area. The various types of soil conservation measures can be recommended to control soil loss according to their suitability. Climatic condition and topographic characteristics of the region were key parameters for deciding suitable land use, and identifying the areas for appropriate soil and water conservation measures in the land.

In the present study the need for soil conservation was estimated from the conservation practice factor (P) required to reduce soil erosion from its average rate on unprotected land to the tolerable rate estimated. This was achieved by recommending reduced conservation practice factor (P) and proper crop cycle. The average rate of erosion covers both the cultivated and the uncultivated parts of the crop and fallow cycle, but the soil conservation measures described only applied and maintained in the cultivated part of the cycle. For Ratnagiri district different crop and fallow cycles of 4-10 years period were tested to reduce soil loss below tolerable limit and get maximum crop years. Hence, by using accurate crop and fallow period cycle, the conservation practice factor were obtained for nine tehsils of Ratnagiri district.

IV. RESULTS AND DISCUSSION

This chapter deals with calculated parameters of USLE for study area, using GIS map. The chapter also deals with estimation of tolerable soil loss and estimation of conservation need factor (P) for study area.

4.1 USLE parameters

4.1.1 Rainfall erosivity (R) Factor

In the present study the relationship between daily rainfall and erosivity factor R data of Wakawali station was used for regression analysis and regression equation was obtained (Fig. 4.1) which has been used to compute R factor for five stations of Ratnagiri district using daily rainfall of 28 years (1984-2011). The average annual rainfall for Hedvi, Karak, Poynar, Dapoli and Wakawali were 3355.72, 3981, 3504, 3497.56 and 3657.36mm, respectively. The average annual erosivity values for different stations were shown in Table 4.1. The average annual erosivity for Hedvi, Karak, Poynar, Dapoli and Wakawali stations were 10,001.93, 10,837.42, 9,734.62, 10,285.58 and 10,117.86 respectively. Hence, the average annual erosivity obtained for Ratnagiri district was 10,195.48 MJ-mm/ha-hr-yr. Using these annual erosivity values R-map of study area was prepared (Fig. 4.2).

Area represented by each rain gauge stations were determined by thissen polygon method. The area under Hedvi, Karak, Poynar, Dapoli and Wakawali stations were 209453.8 ha, 327465.2 ha, 178385.6 ha, 74000.96 ha and 56839.75 ha, respectively. Average annual erosivity for Karak was highest as compared to other rain gauge stations. This was because average annual rainfall of Karak was higher (3981mm).

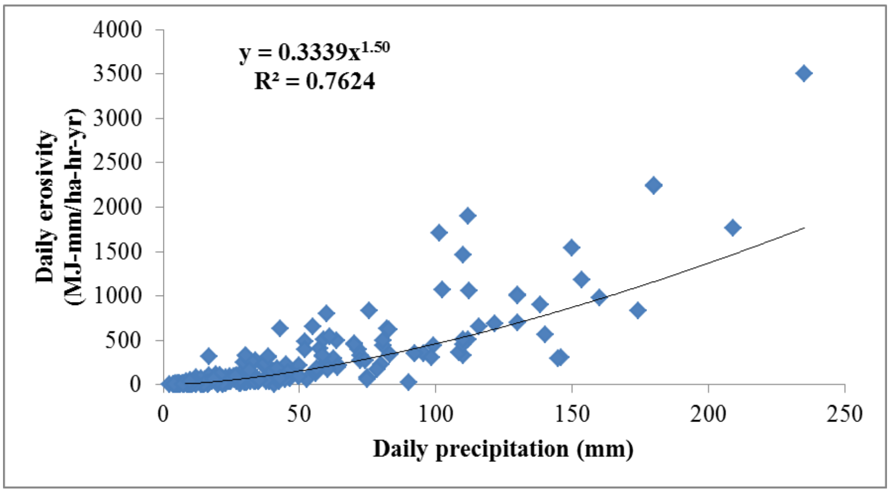

Fig. 4.1 Relationship between daily erosivity index and daily precipitation

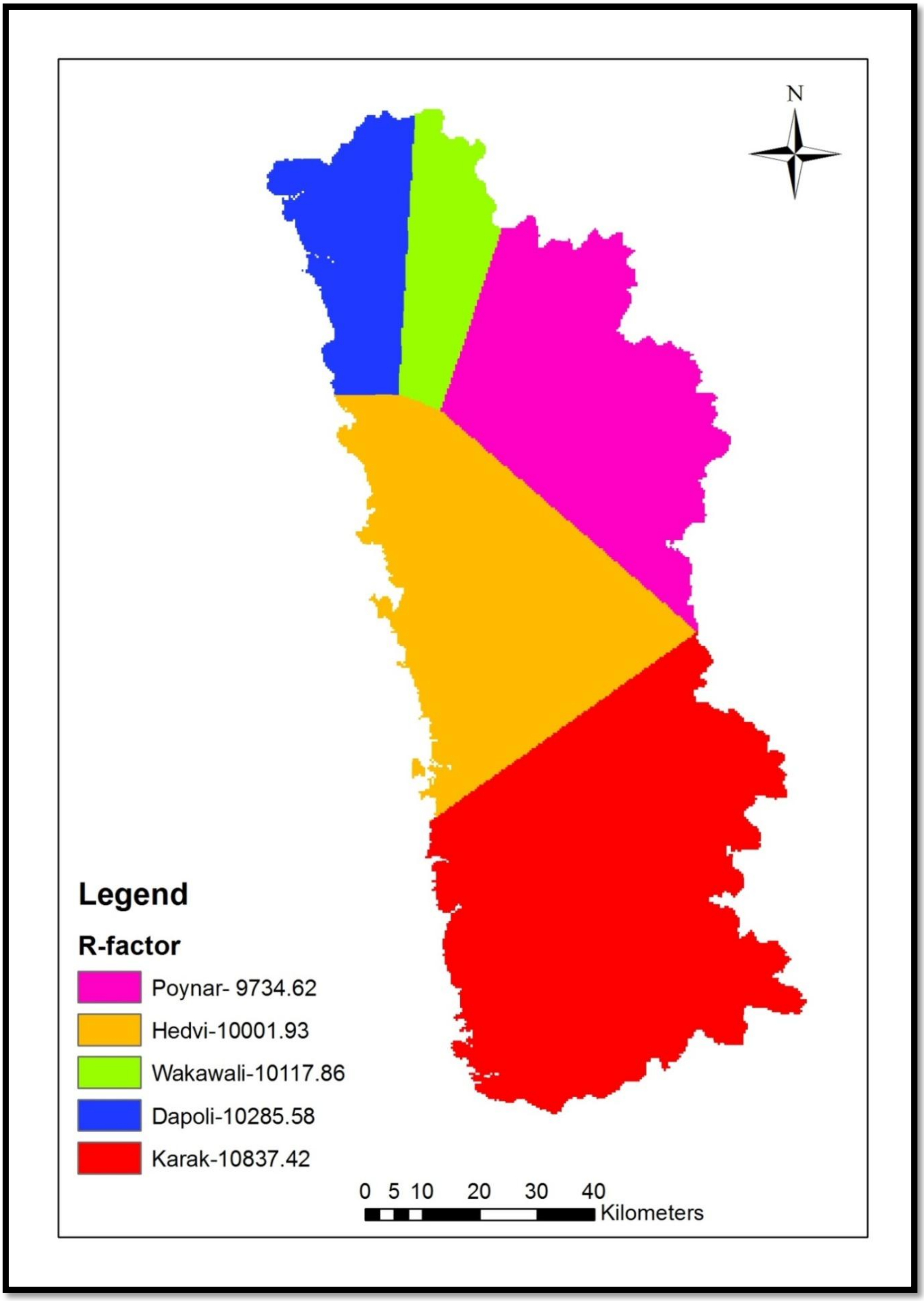

Fig. 4.2 Rainfall Erosivity map of Ratnagiri district

Table 4.1. Annual erosivity values for different stations for Ratnagiri district

Year	Annual Erosivity(MJ-mm/ha-hr-yr)				
	Hedvi	Karak	Poynar	Dapoli	Wakawali
1984	6243.165	11491.66	8956.307	8763.078	9178.884
1985	10124.34	11545.16	11879.64	18553.73	14233.5
1986	4531.426	8445.705	7478.409	6870.538	7589.621
1987	12199.23	8758.438	9892.123	7104.74	11378.1
1988	6360.044	11919.52	9674.822	8506.066	9906.996
1989	11341.43	11127.26	7879.426	8546.639	8913.906
1990	8780.12	10738.5	11494.98	16858.81	10893.56
1991	6928.019	10000.35	13040.33	12692.51	12324.58
1992	8077.97	10460.01	8874.317	8332.443	8240.417
1993	16604.87	11836.03	13301.04	10738.28	13433.77
1994	9143.002	11956.44	7456.621	6955.01	6841.76
1995	9117.098	9260.848	8778.919	8004.951	7346.479
1996	9142.886	7884.651	7959.894	7894.98	7351.488
1997	10523.69	13111.7	8936.006	11734.66	9994.141
1998	10688.2	12295.49	7865.78	10704.05	8535.273
1999	6045.265	11004.56	8106.74	11658.65	8420.364
2000	18502.47	8926.215	12210.29	14889.87	10952.87
2001	6226.609	8530.745	5296.442	5501.914	10739.94
2002	5776.818	8492.515	6994.114	6611.719	10692.75
2003	8357.902	6747.831	8096.184	7944.704	8767.681
2004	10563.82	10772.27	10164.25	9848.399	9499.756
2005	15711.39	15053.73	14932.27	10625.12	10577.31

2006	7754.855	13706.56	10014.35	8908.508	10087.67
2007	9424.4	13193.13	12211.79	14111.45	12291.53
2008	8694.531	11483.7	8828.015	8189.539	12168.42
2009	9579.83	9059.073	7198.412	6452.038	8211.196
2010	19917.27	11346.01	11079.43	14849.55	11233.46
2011	13693.51	14299.84	13968.71	16144.54	13494.82
Average	**10001.93**	**10837.42**	**9734.62**	**10285.58**	**10117.86**

4.1.2 Soil Erodibility Factor (K)

Soil erodibility factor were calculated for 45 villages of Ratnagiri district, where the data of sand, silt, clay and organic carbon were available (Thawakar, 2014).

Estimated per cent distribution of sand in soils of Ratnagiri district was found to vary from 23.73 to 62.7 % with a mean value of 43.22 %. Ratnagiri district soils have silt content in the range of 13.49 to 52.16 % with the mean value of 36.83 % and clay content varied from 12.97 to 29.4 % with the mean value of 21.19 %. In general, textural classes for Ratnagiri district was found to be in the category of loam type. In Ratnagiri district, organic carbon was found to be in the range of 0.14 to 1.98 per cent with the mean value of 1.06 per cent. Organic matter of Ratnagiri district varied from 0.2 to 3.4 per cent with the mean value of 1.8 per cent. Hydraulic conductivity was determined by using the SPAW model. Hydraulic conductivity for Ratnagiri district is varied from 2.64 to 25.32 cm/hr (APPENDIX IV). The permeability of soils of 45 villages of Ratnagiri district were obtained from hydraulic conductivity of soil. The permeability classes varied between moderate to rapid class and rapid class and accordingly permeability codes were assigned as 2 and 1 respectively. Soil erodibility factor for different villages of Ratnagiri district were found in the range of 0.0346 to 0.0636 t-ha-hr/ha-MJ-mm. Accordingly, K factor map of Ratnagiri district was prepared (Fig.4.3).

4.1.3 Topographic Factor (LS)

Digital elevation model (DEM) of the study area was prepared using SRTM data. A slope map was created from the DEM based on the slope map, slope length (L) and slope gradient(S) maps and finally a layer of LS factor was generated. The values of LS factor for study area was found in the range of 1.953 to 4.393. LS factor map of Ratnagiri district was prepared (Fig.4.4). Major portion of

Ratnagiri district was covered by LS factor ranging between 2 to 3 (85.42%), followed by 1 to 2 (14.25%) and 3 to 4 (0.34%). Very small portion of the study area was covered by LS factor more than 4 (0.001 %).

4.1.4 Crop Management Factor (C)

GIS technique has a potential to generate a thematic layer of land use land cover of a region. LANDSAT images were used for preparation of land use land cover map. The land use/cover classification of the study area was carried out using supervised classification (maximum likelihood classification). Classification was carried out for five land use classes: forest, agricultural land, waterbody, barren land and urban area. Information on land use permits a better understanding of the land utilization aspects of cropping pattern, forest, agriculture area and urban area which were important for development or planning of erosion studies. Crop management factor (C) values for study area were ranging from 0.024 to 0.12. C factor for different land cover class were shown in Table 4.2. C factor map of Ratnagiri district was prepared (Fig 4.5).

Table 4.2. C values for different land use/land cover

Land use/land cover	C value
Forest	0.04
Barren land	0.034
Built-up	0.024
Horticultural crops	0.1
Oilseeds	0.28
Rice	0.15

4.1.5 Conservation Practice Factor (P)

The value of P factor was considered as 1 for Ratnagiri district as it was untreated. With P value as 1, P map as shown in Fig.4.6 was prepared and used in USLE for calculating soil loss.

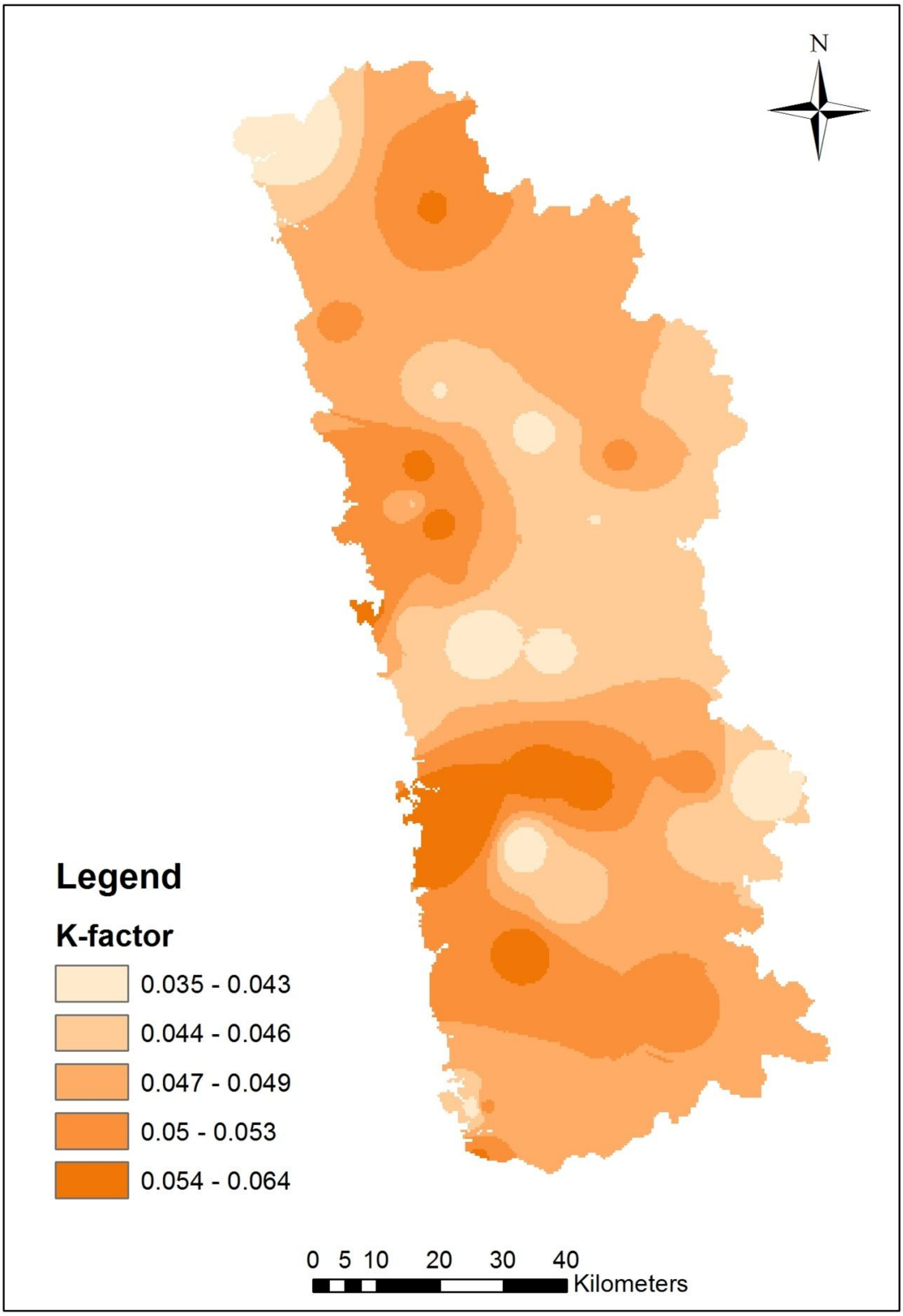
N
Legend
K-factor
0.035 - 0.043
0.044 - 0.046
0.047 - 0.049
0.05 - 0.053
0.054 - 0.064
0 5 10 20 30 40
Kilometers

Fig. 4.3 Soil erodibility map of Ratnagiri district

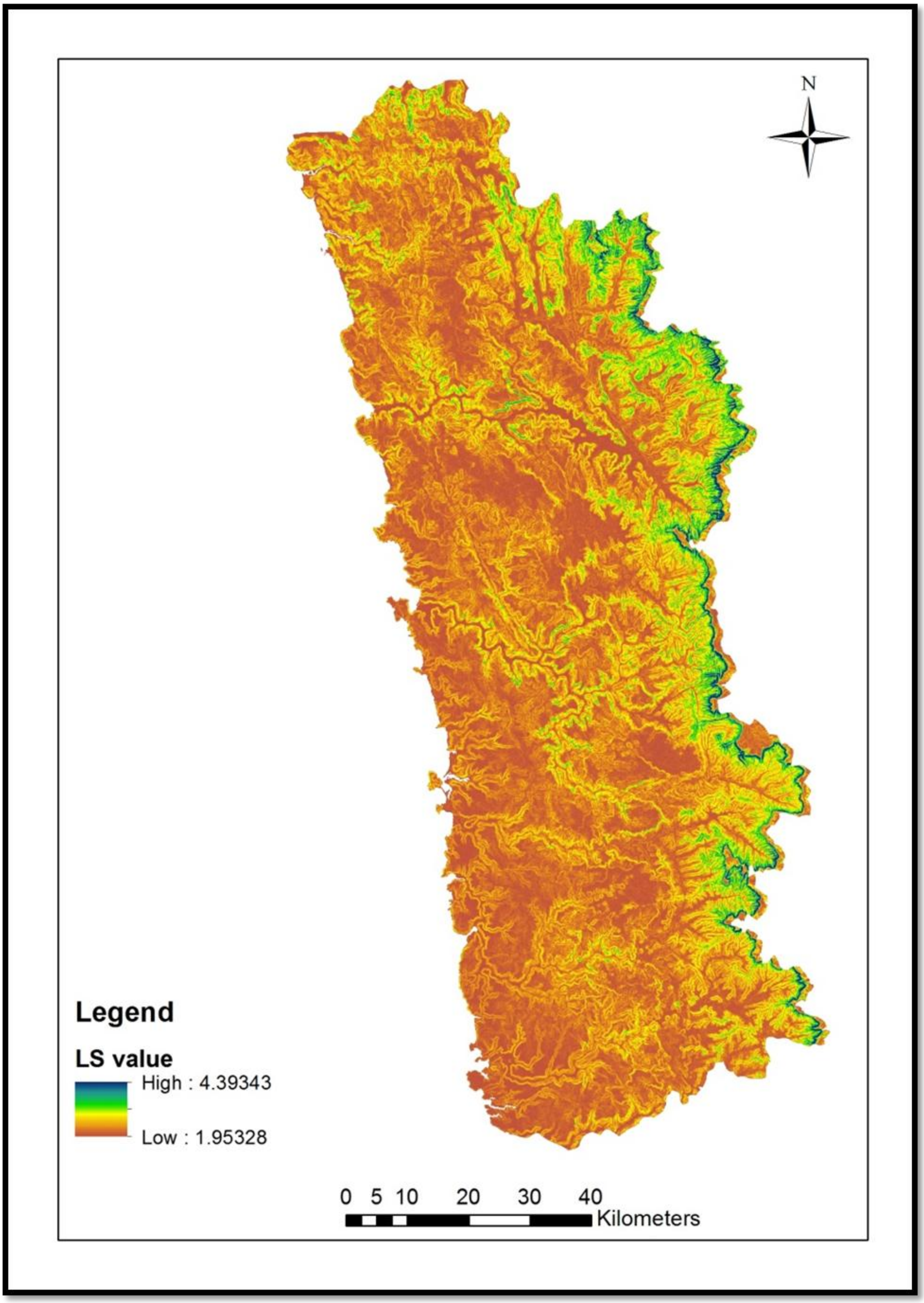

Fig. 4.4 Topographic factor map of Ratnagiri district

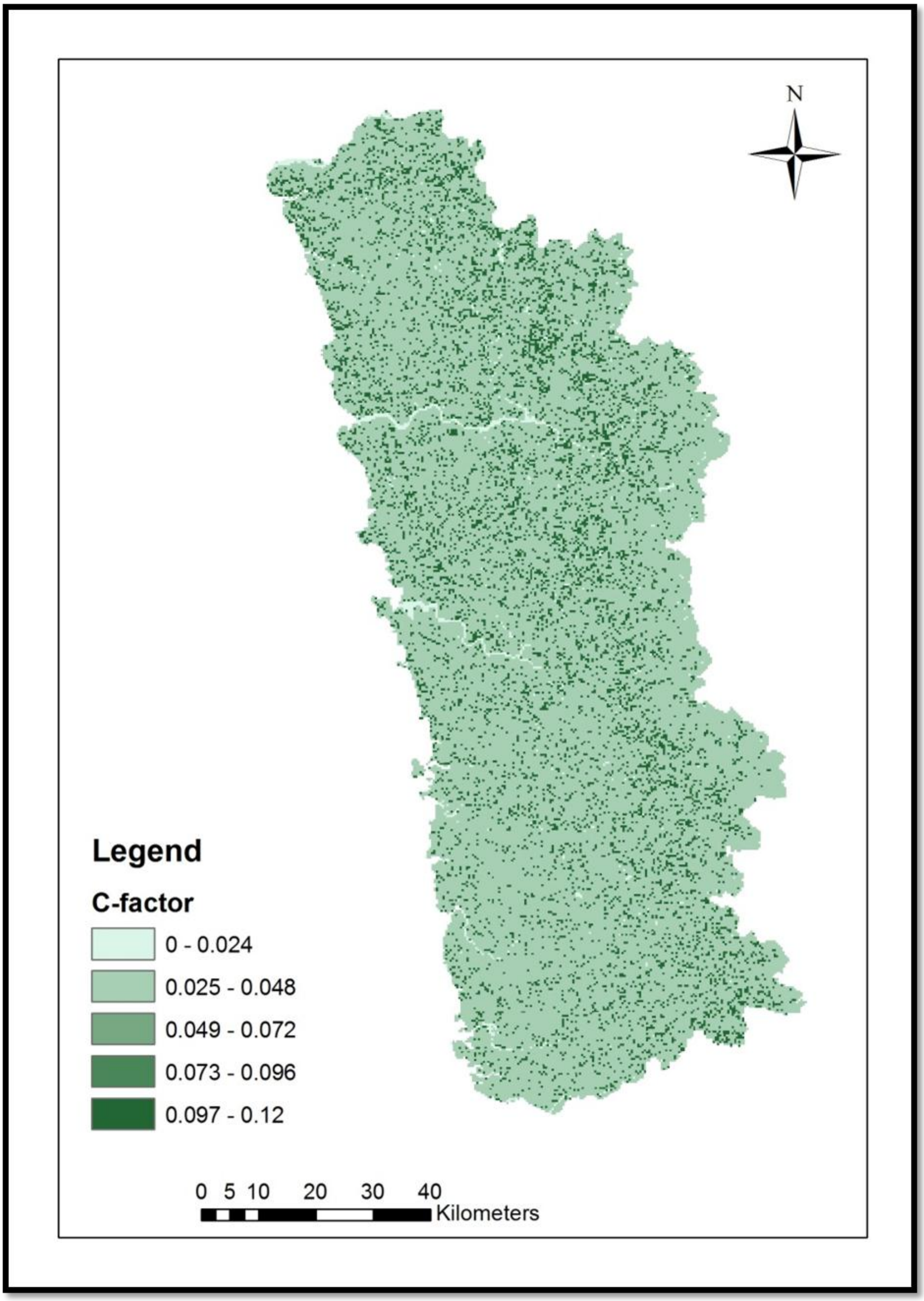

Fig. 4.5 Crop cover management map of Ratnagiri district

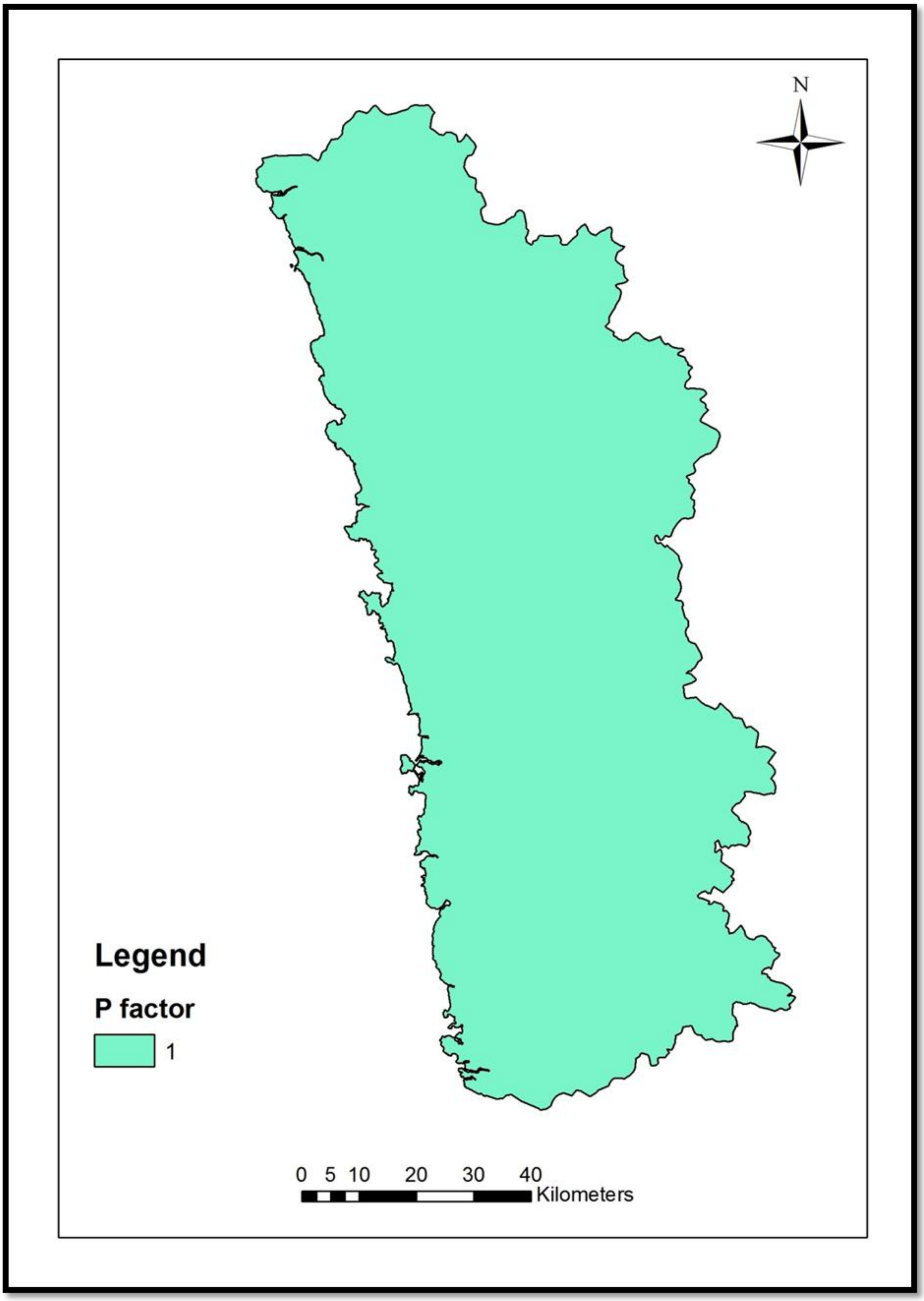

Fig. 4.6 Conservation practice map of Ratnagiri district

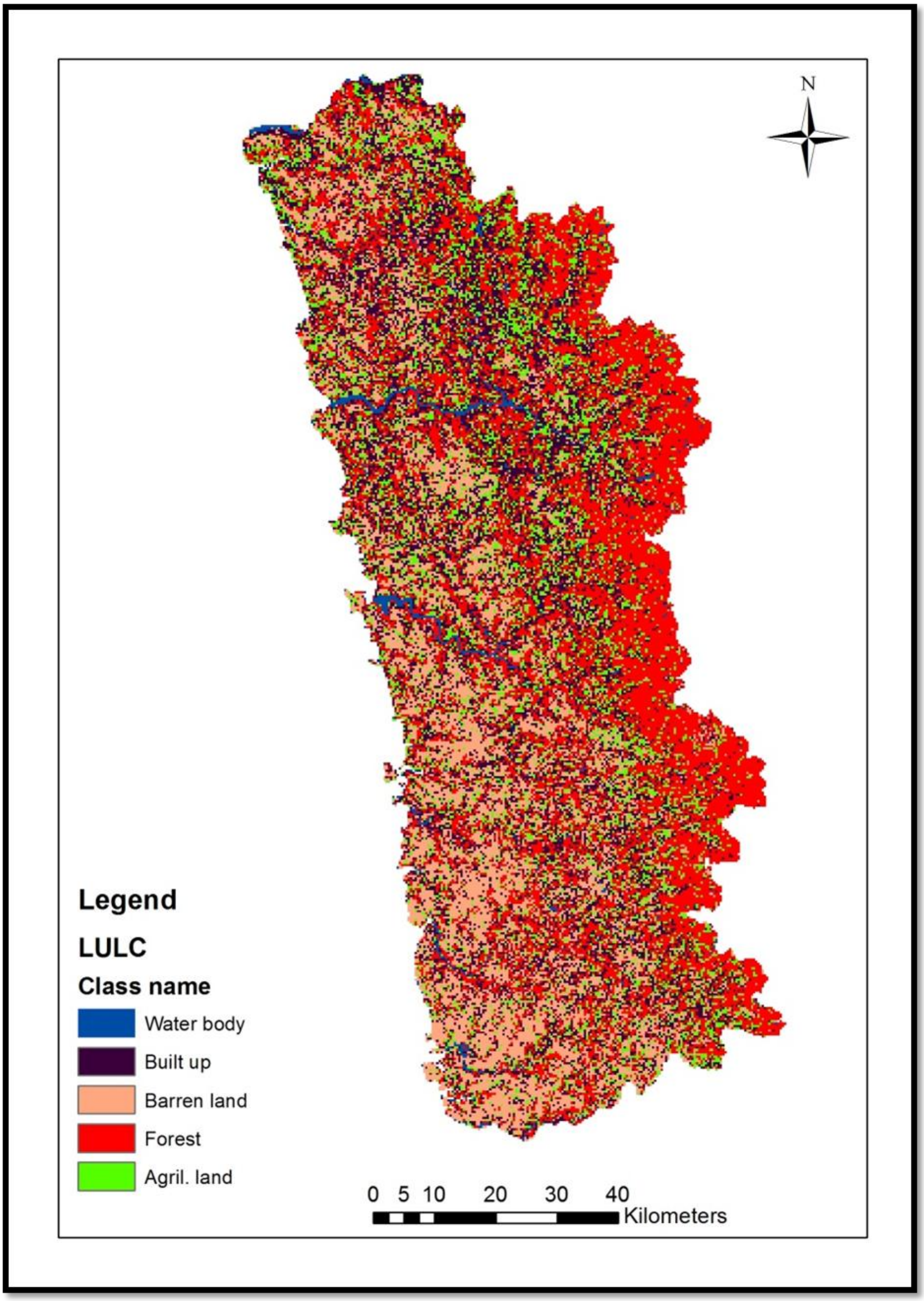

Fig.4.7 LU/LC map of Ratnagiri district

4.2 Average Annual Soil Loss using USLE

The annual soil loss for study area was calculated by annual average R (based on annual average rainfall data of 1984-2011) and K, LS, C and P factors. The soil erosion rates (t/ha/yr) were estimated for study area. All the layers viz. R, K, LS, C and P were generated in GIS and were overlaid to obtain the product, which gave annual soil loss of the study area. Average annual soil loss from study area was 43.61 t/ha/yr (Fig. 4.8). The classification of soil erosion has been given in 6 categories of soil loss.

Classification of study area was done into six classes as slight, moderate, high, very high, severe, and very severe as per criteria given by Singh *et.al.* (1992) (Table 4.3).

Table 4.3. Area under different classes of soil erosion before conservation measures for Ratnagiri district

Soil erosion class	Soil loss (t/ha/yr)	Area (ha)	Per cent area
Slight	0-5	10868.86	1.30
Moderate	5-10	34641.46	4.14
Moderately severe	10-20	95689.16	11.42
Severe	20-40	390953.6	46.67
Very severe	40-80	186843.2	22.31
Extremely severe	>80	118677.4	14.17

Area under slight erosion class was found to be 10,868.86 ha, moderate erosion class was 34,641.46 ha, moderately severe erosion class was 95,689.16 ha, severe erosion class was 3,90,953.6 ha, very severe erosion class was 1,86,843.2 ha and extremely severe erosion class was 1,18,677.4 ha. Highest per cent of area was found under the severe soil erosion class of (46.67 %), followed by very severe (22.31 %), extremely severe (14.17 %), moderately severe (11.42 %), moderate (4.14 %) and slight (1.30 %) before recommendation of soil and water conservation measures (Table 4.3). It showed that more than 80 per cent of area comes under severe to extremely severe erosion class which was cause of concern. This proves the high need of soil and water conservation measures in the watershed for the sustainable management of natural resources. Tehsils wise area under different classes of soil erosion before conservation measures of Ratnagiri district as shown in Table 4.4.

Table 4.4. Tehsils wise Area under different classes of soil erosion before conservation measures of Ratnagiri district

Area under each class (ha)						
Soil erosion class (t/ha/yr) / Tehsil	Slight (0-5)	Moderate (5-10)	Moderately severe (10-20)	Severe (20-40)	Very severe (40-80)	Extremely severe (>80)
Chiplun	1349.74	3897.35	17159.93	55256.1	14991.76	17265.24
Dapoli	993.94	3826.9	10544.24	48534.29	13203.93	13140.35
Guhagar	2057.04	3383.2	7681.693	37282.31	8747.092	10468.58
Khed	2063.6	4596.365	10018.91	40749.54	26270.26	18830.17
Lanja	969.14	2393.769	6578.55	29444	26889	9101.03
Mandangad	848.91	2878.45	5500.32	20950.24	6963.95	8175.011
Rajapur	1448.08	2466.54	13178.83	57621.95	31986.23	14739.04
Ratnagiri	1318.58	1773.654	10882.5	54893.18	14971.56	10231.25
Sangameshwar	637.078	5469.135	14144.089	46233.55	42822.96	16716.74

4.3 Tolerable soil loss

Estimation of tolerable soil loss has been done (i) through value of yield loss that can be tolerated or (ii) the proportion of land (per cent) that can be allowed to make the depth of soil shallower at least by one soil depth class over a specified time period. It has been found that these two ways to estimate the soil loss do not produce same values. The tolerable soil losses for nine tehsils of Ratnagiri district were estimated over a specified time period of 100 years. The tolerable soil loss calculated through the second method (Eqn. 3.14) often produces a lower estimate than first method (Eqn. 3.13) which was shown in table 4.4 to 4.11. Estimated average tolerable soil loss (t/ha/yr) for Ratnagiri district was 3.09 t/ha/yr for moderately shallow soil, 9.25 t/ha/yr for moderately deep soil, 15.42 t/ha/yr for deep soil and 18.50 t/ha/yr for very deep soil with low soil susceptibility (25%) over 100 year period.

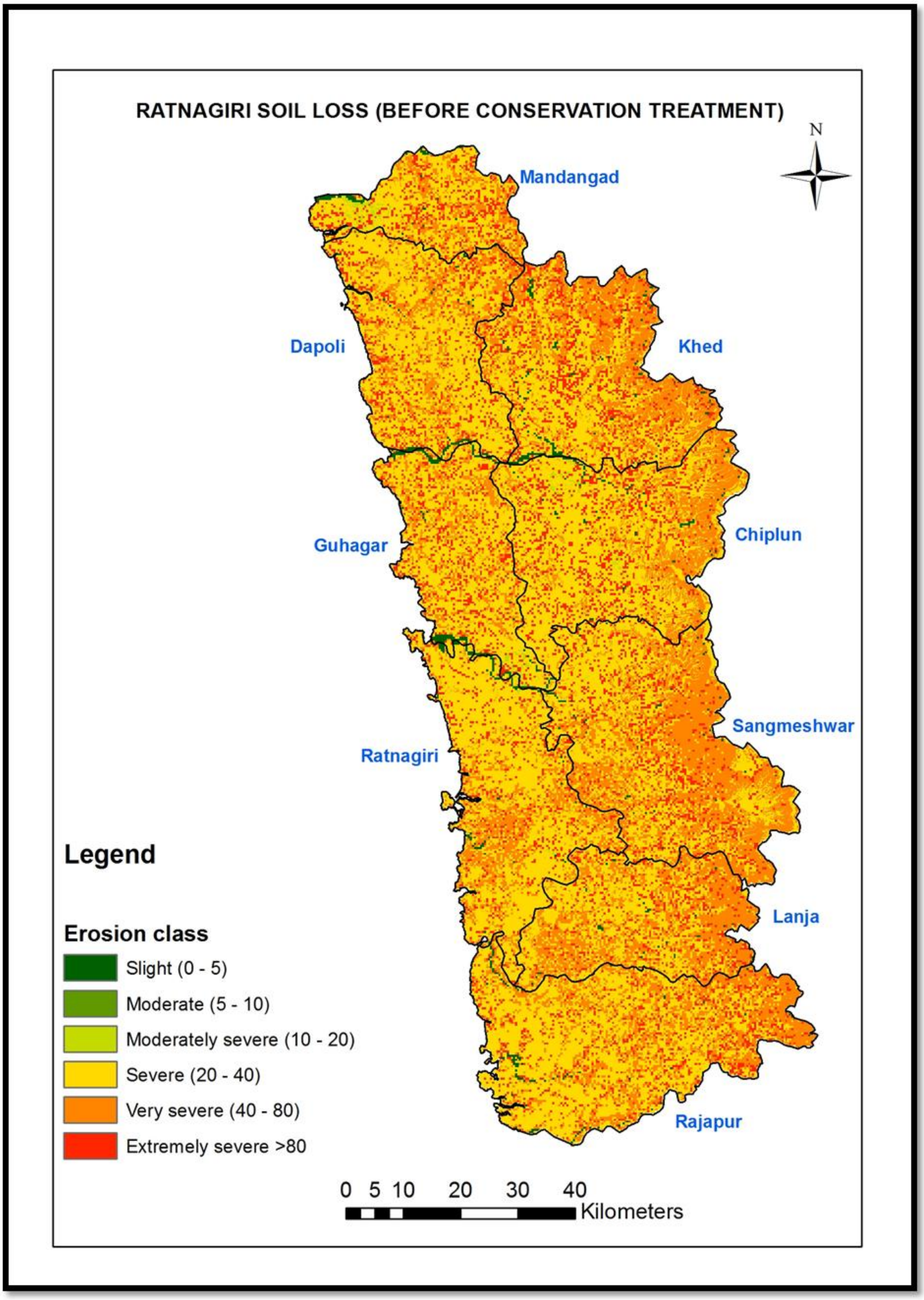

Fig 4.8 Average annual soil loss map of Ratnagiri district before conservation measures

4.3.1 Proportion of land downgraded from given classes due to soil loss in Ratnagiri district (over a 100 year period)

Table 4.5. Proportion of land downgraded from given classes due to soil loss in Mandangad and Chiplun tehsils of Ratnagiri district (over a 100 year period)

Mandangad and Chiplun						
Soil depth class and change (cm)	**Amount of land lost (% of class) at erosion rates (t/ha/yr)**					
	5	**10**	**25**	**50**	**75**	**100**
From shallow (<25 cm) to bedrock (0)	15.87	31.75	79.37	100		
From moderately shallow (25-50 cm) to shallow (<25 cm)	15.87	31.75	79.37	100		
From moderately deep (50-100 cm) to moderately shallow (25-50 cm)	5.29	10.58	26.46	52.91	79.37	100
From deep (100-150 cm) to moderately deep (50-100 cm)	3.17	6.35	15.87	31.75	47.62	63.49
From very deep (>150 cm) to deep (100-150 cm)	2.65	5.29	13.23	26.46	39.68	52.91

The proportion of land downgraded may be calculated by (Eqn. 3.9). It was observed that from shallow soils (<25 cm) soil depth class, at moderate rate of erosion (SL = 5 t/ha/yr), with T = 100 years, BD = 1.26 Mg/m^3 and D = 25 cm, the proportion of land downgraded (P) was 15.87% (Table 4.5) for Mandangad and Chiplun tehsils of Ratnagiri district. Also from moderately shallow, moderately deep and deep soil depth classes, the proportion of land downgraded were 15.87%, 5.29% and 3.17% respectively with SL = 5 t/ha/yr.

Similarly, it was observed that from shallow soils (<25 cm) soil depth class, at 50 t/ha/yr rate of soil erosion, with T = 100 years, BD = 1.26 Mg/m^3 and D = 25 cm, the proportion of land downgraded was 100%. Since at 100 % loss, no soil was existing, a P value of 100 has been accepted. It was obvious that a deep soil was losing less proportion of land as compared to the shallow depth class of soil. Thus, very deep soils have been degraded to deep soil at an erosion rate of 5 t/ha/yr over 100 year period and lose only 2.65 % land (Table 4.5).

Guhagar and Sangmeshwar						
Soil depth class and change (cm)	**Amount of land lost (% of class) at erosion rates (t/ha/yr)**					
	5	**10**	**25**	**50**	**75**	**100**
From shallow (<25 cm) to bedrock (0)	16.39	32.79	81.97	100		
From moderately shallow	16.39	32.79	81.97	100		

Table 4.6. Proportion of land downgraded from given classes due to soil loss in Guhagar and Sangmeshwar3 tehsils of Ratnagiri district (over a 100 year period)

(25-50 cm) to shallow (<25 cm)						
From moderately deep (50-100 cm) to moderately shallow (25-50 cm)	5.46	10.93	27.32	54.64	81.97	100
From deep (100-150 cm) to moderately deep (50-100 cm)	3.28	6.56	16.39	32.79	49.18	65.57
From very deep (>150 cm) to deep (100-150 cm)	2.73	5.46	13.66	27.32	40.98	54.64

The proportion of land downgraded may be calculated by (Eqn.3.9). It was observed that from shallow soils (<25 cm) soil depth class, at moderate rate of erosion (SL = 5 t/ha/yr), with T = 100 years, BD = 1.22 Mg/m^3 and D = 25 cm, the proportion of land downgraded (P) was 16.39% (Table 4.6) for Guhagar and Sangmeshwar tehsils of Ratnagiri district. Also from moderately shallow, moderately deep and deep soil depth classes, the proportion of land downgraded were 16.39%, 5.46% and 3.28% respectively with SL = 5 t/ha/yr.

Similarly, it was observed that from shallow soils (<25 cm) soil depth class, at 50 t/ha/yr rate of soil erosion, with T = 100 years, BD = 1.22 Mg/m^3 and D = 25 cm, the proportion of land downgraded was 100%. Since at 100 % loss, no soil was existing, a P value of 100 has been accepted. It was obvious that a deep soil was losing less proportion of land as compared to the shallow depth class of soil. Thus, very deep soils have been degraded to deep soil at an erosion rate of 5 t/ha/yr over 100 year period and lose only 2.73 % land (Table 4.6).

Table 4.7. Proportion of land downgraded from given classes due to soil loss in Khed, Ratnagiri, Lanja and Dapoli tehsils of Ratnagiri district (over a 100 year period)

Khed, Ratnagiri, Lanja and Dapoli						
Soil depth class and change (cm)	**Amount of land lost (% of class) at erosion rates (t/ha/yr)**					
	5	**10**	**25**	**50**	**75**	**100**

From shallow (<25 cm) to bedrock (0)	16.26	32.52	81.30	100		
From moderately shallow (25-50 cm) to shallow (<25 cm)	16.26	32.52	81.30	100		
From moderately deep (50-100 cm) to moderately shallow (25-50 cm)	5.42	10.84	27.10	54.20	81.30	100
From deep (100-150 cm) to moderately deep (50-100 cm)	3.25	6.50	16.26	32.52	48.78	65.04
From very deep (>150 cm) to deep (100-150 cm)	2.71	5.42	13.55	27.10	40.65	54.20

The proportion of land downgraded may be calculated by (Eqn.3.9). It was observed that from shallow soils (<25 cm) soil depth class, at moderate rate of erosion (SL = 5 t/ha/yr), with T = 100 years, BD = 1.23 Mg/m^3 and D = 25 cm, the proportion of land downgraded (P) was 16.26% (Table 4.7) for Khed, Ratnagiri, Lanja and Dapoli tehsils of Ratnagiri district. Also from moderately shallow, moderately deep and deep soil depth classes, the proportion of land downgraded were 16.26%, 5.42% and 3.25% respectively with SL = 5 t/ha/yr.

Similarly, it was observed that from shallow soils (<25 cm) soil depth class, at 50 t/ha/yr rate of soil erosion, with T = 100 years, BD = 1.23 Mg/m^3 and D = 25 cm, the proportion of land downgraded was 100%. Since at 100 % loss, no soil was existing, a P value of 100 has been accepted. It was obvious that a deep soil was losing less proportion of land as compared to the shallow depth class of soil. Thus, a very deep soil has been degraded to deep soil at an erosion rate of 5 t ha^{-1} yr^{-1} over 100 year period and lose only 2.71 % land (Table 4.7).

Table 4.8. Proportion of land downgraded from given classes due to soil loss in Rajapur tehsil of Ratnagiri district (over a 100 year period)

Rajapur						
Soil depth class and change (cm)	**Amount of land lost (% of class) at erosion rates (t/ha/yr)**					
	5	**10**	**25**	**50**	**75**	**100**
From shallow (<25 cm) to bedrock (0)	16	32	80	100		
From moderately shallow (25-50 cm) to shallow (<25 cm)	16	32	80	100		
From moderately deep (50-100 cm) to moderately shallow (25-50 cm)	5.33	10.67	26.67	53.33	80	100
From deep (100-150 cm) to moderately deep (50-100 cm)	3.2	6.4	16	32	48	64
From very deep (>150 cm) to deep (100-150 cm)	2.67	5.33	13.33	26.67	40	53.33

The proportion of land downgraded may be calculated by Eqn. (3.9). It was observed that from shallow soils (<25 cm) soil depth class, at moderate rate of erosion (SL = 5 t/ha/yr), with T = 100 years, BD = 1.25 Mg/m^3 and D = 25 cm, the proportion of land downgraded (P) was 16.00% (Table 4.8) for Rajapur tehsil of Ratnagiri district. Also from moderately shallow, moderately deep and deep soil depth classes, the proportion of land downgraded were 16.00%, 5.33% and 3.2% respectively with SL = 5 t/ha/yr.

Similarly, it was observed that from shallow soils (<25 cm) soil depth class, at 50 t/ha/yr rate of soil erosion, with T = 100 years, BD = 1.23 Mg/m^3 and D = 25 cm, the proportion of land downgraded was 100%. Since at 100 % loss, no soil was existing, a P value of 100 has been accepted. It was obvious that a deep soil was losing less proportion of land as compared to the shallow depth class of soil. Thus, very deep soils have been degraded to deep soil at an erosion rate of 5 t/ha/yr over 100 year period and lose only 2.67 % land (Table 4.8).

4.3.2 Tolerable soil loss (t/ha/yr) equivalent to 10 % P of the proportion of land downgraded and > 50 % reduction in crop yield at low input level over 100 years in Ratnagiri district (calculation assumes a minimum of 25 cm depth for crop production)

Table 4.9. Tolerable soil loss (t/ha/yr) equivalent to 10 % P of the proportion of land downgraded and > 50 % reduction in crop yield at low input level over 100 years in Mandangad and Chiplun tehsils of Ratnagiri district

Mandangad and Chiplun						
Soil susceptibility	**Low Rm= 25%**		**Intermediate Rm= 50%**		**High Rm= 175%**	
	Eqn. (3.9)	Eqn. (3.8)	Eqn. (3.9)	Eqn. (3.8)	Eqn. (3.9)	Eqn. (3.8)
Shallow (<25)	0	0	0	0	0	0
Moderately shallow (25-50)	3.15	66	3.15	34.5	3.15	12
Moderately deep (50-100)	9.45	66	9.45	34.5	9.45	12
Deep (100-150)	15.75	66	15.75	34.5	15.75	12
Very deep (>150)	18.9	66	18.9	34.5	18.9	12

For depth of shallow soil is <25 cm, which is the minimum requirement for crop production. Therefore, soil loss was nil. For moderately shallow depth soils (25-50 cm) and low soil susceptibility (25 %) with T = 100 years, BD = 1.26 Mg/ m^3 and D = 25 cm, the tolerable soil loss was estimated as 3.15 t/ha/yr from Eqn. (3.9) for Mandangad and Chiplun tehsils of Ratnagiri district (Table 4.9). Similarly, for same moderately shallow depth soils (25-50 cm) and low soil susceptibility (25 %) with T = 100 years, BD = 1.26 Mg/m^3 and D = 25 cm and Rm = 25 %, the soil loss was estimated as 66 t/ha/yr by Eqn. (3.8). Since the Eqn. (3.9), in general gives the lower value than the Eqn. (3.8), the tolerable soil loss was accepted. The corresponding values using Eqn. (3.8) for intermediate and high soil susceptibility classes with Rm = 50% and Rm = 175% were 34.5 and 12 t/ha/yr respectively, which were higher than the (3.15 t/ha/yr) obtained using Eqn. (3.9). For deep and very deep soils, under high susceptibility soil class, the values obtained using Eqn. (3.8) were lower (12 t/ha/yr) and hence accepted.

Table 4.10. Tolerable soil loss (t/ha/yr) equivalent to 10 % P of the proportion of land downgraded and > 50 % reduction in crop yield at low input level over 100 years in Guhagar and Sangmeshwar tehsils of Ratnagiri district

Guhagar and Sangmeshwar						
Soil susceptibility	**Low Rm= 25%**		**Intermediate Rm= 50%**		**High Rm= 175%**	
	Eqn. (3.9)	Eqn. (3.8)	Eqn. (3.9)	Eqn. (3.8)	Eqn. (3.9)	Eqn. (3.8)
Shallow (<25)	0	0	0	0	0	0
Moderately shallow (25-50)	3.05	64	3.05	33.5	3.05	11.71
Moderately deep (50-100)	9.15	64	9.15	33.5	9.15	11.71
Deep (100-150)	15.25	64	15.25	33.5	15.25	11.71
Very deep (>150)	18.3	64	18.3	33.5	18.3	11.71

For moderately shallow depth soils (25-50 cm) and low soil susceptibility (25 %) with T = 100 years, BD = 1.22 Mg/m^3 and D = 25 cm, the tolerable soil loss was estimated as 3.05 t/ha/yr from Eqn. (3.9) for Guhagar and Sangmeshwar tehsils of Ratnagiri district (Table 4.10). Similarly, for same moderately shallow depth soils (25-50 cm) and low soil susceptibility (25 %) with T = 100 years, BD = 1.22 Mg/m^3 and D = 25 cm and Rm = 25%, the soil loss was estimated as 64 t/ha/yr by Eqn. (3.8). Since the Eqn. (3.9), in general gives the lower value than the Eqn. (3.8), the tolerable soil loss was accepted. The corresponding values using Eqn. (3.8) for intermediate and high soil susceptibility classes with Rm = 50% and Rm = 175% were 33.5 and 11.71 t/ha/yr respectively, which were higher than the (3.05 t/ha/yr) obtained using Eqn. (3.9). For deep and very deep soils, under high susceptibility soil class, the values obtained using Eqn. (3.8) were lower (11.71 t/ha/yr) and hence accepted.

Table 4.11. Tolerable soil loss (t/ha/yr) equivalent to 10 % P of the proportion of land downgraded and > 50 % reduction in crop yield at low input level over 100 years in Khed, Ratnagiri, Lanja and Dapoli tehsils of Ratnagiri district

Khed, Ratnagiri, Lanja and Dapoli						
Soil susceptibility	**Low Rm= 25%**		**Intermediate Rm= 50%**		**High Rm= 175%**	
	Eqn. (3.9)	Eqn. (3.8)	Eqn. (3.9)	Eqn. (3.8)	Eqn. (3.9)	Eqn. (3.8)
Shallow (<25)	0	0	0	0	0	0
Moderately shallow (25-50)	3.08	64.5	3.08	33.75	3.08	11.79
Moderately deep (50-100)	9.23	64.5	9.23	33.75	9.23	11.79
Deep (100-150)	15.38	64.5	15.38	33.75	15.38	11.79
Very deep (>150)	18.45	64.5	18.45	33.75	18.45	11.79

For moderately shallow depth soils (25-50 cm) and low soil susceptibility (25%) with T = 100 years, BD = 1.23 Mg/m^3 and D = 25 cm, the tolerable soil loss was estimated as 3.08 t/ha/yr from Eqn. (3.9) for Khed, Ratnagiri, Lanja and Dapoli tehsils of Ratnagiri district (Table 4.11). Similarly, for same moderately shallow depth soils (25-50 cm) and low soil susceptibility (25%) with T = 100 years, BD = 1.23 Mg/m^3 and D = 25 cm and Rm = 25%, the soil loss was estimated as 64.5 t/ha/yr by Eqn. (3.8). Since the Eqn. (3.9), in general gives the lower value than the Eqn. (3.8), the tolerable soil loss was accepted. The corresponding values using Eqn. (3.8) for intermediate and high soil susceptibility classes with Rm = 50% and Rm = 175% were 33.75 and 11.79 t/ha/yr respectively, which were higher than the (3.08 t/ha/yr) obtained using Eqn. (3.9). For deep and very deep soils, under high susceptibility soil class, the values obtained using Eqn. (3.8) were lower (11.79 t/ha/yr) and hence accepted.

Table 4.12. Tolerable soil loss (t/ha/yr) equivalent to 10 % P of the proportion of land downgraded and > 50 % reduction in crop yield at low input level over 100 years in Rajapur tehsil of Ratnagiri district

Rajapur						
Soil susceptibility	**Low Rm= 25%**		**Intermediate Rm= 50%**		**High Rm= 175%**	
	Eqn. (3.9)	Eqn. (3.8)	Eqn. (3.9)	Eqn. (3.8)	Eqn. (3.9)	Eqn. (3.8)
Shallow (<25)	0	0	0	0	0	0
Moderately shallow (25-50)	3.13	65.5	3.125	34.25	3.125	11.93
Moderately deep (50-100)	9.38	65.5	9.375	34.25	9.375	11.93
Deep (100-150)	15.63	65.5	15.625	34.25	15.625	11.93
Very deep (>150)	18.75	65.5	18.75	34.25	18.75	11.93

For moderately shallow depth soils (25-50 cm) and low soil susceptibility (25%) with T = 100 years, BD = 1.25 Mg/m^3 and D = 25 cm, the tolerable soil loss was estimated as 3.13 t/ha/yr from Eqn. (3.9) for Rajapur tehsil of Ratnagiri district (Table 4.12). Similarly, for same moderately shallow depth soils (25-50 cm) and low soil susceptibility (25%) with T = 100 years, BD = 1.25 Mg/m^3 and D = 25 cm and Rm = 25 %, the soil loss was estimated as 65.5 t/ha/yr by Eqn. (3.8). Since the Eqn. (3.9), in general gives the lower value than the Eqn. (3.8), the tolerable soil loss was accepted. The corresponding values using Eqn. (3.8) for intermediate and high soil susceptibility classes with Rm = 50% and Rm = 175% were 34.25 and 11.93 t/ha/yr respectively, which were higher than the (3.13 t/ha/yr) obtained using Eqn. (3.9). For deep and very deep soils, under high susceptibility soil class, the values obtained using Eqn. (3.8) were lower (11.93 t/ha/yr) and hence accepted.

4.4 Total annual soil loss in Ratnagiri district

In Ratnagiri, total six classes of soil erosion were identified. Taking the median values of the soil erosion range, the total soil lost under different erosion classes was estimated (Table 4.13). Topsoil formation at the rate of 1 mm/year was equivalent to an annual addition of 13.3 tons/ha, taking into account the weight of a hectare furrow slice (15 cm depth) soil as 2.2 x 10^6 kg (Bhattacharya *et al*., 2007). Since, Ratnagiri represents a tropical wet climate; the soil formation rate of 2.0 mm should be equivalent to an annual addition of (2.2 x 10^6/150) x 2.0 = 29 tons/ha soil. Hence, there was an estimated annual addition of 29 tons soil in a hectare in Ratnagiri district.

Table 4.13. Total annual soil loss in Ratnagiri

Soil erosion class	Range (t/ha/yr)	Area (ha)	Soil loss (million tons)/yr
Slight	0-5	10868.86	0.03
Moderate	5-10	34641.46	0.26
Moderately severe	10-20	95689.16	1.44
Severe	20-40	390953.6	11.73
Very severe	40-80	186843.2	11.21
Extremely severe	>80	118677.4	11.87
Total	-	837673.7	36.53
Effective soil loss	-		34.81

Area under slight erosion class was found to be 10,868.86 ha with annual soil loss of 0.03 Mt/yr, moderate erosion class was 34,641.46 ha with annual soil loss of 0.26 Mt/yr, moderately severe erosion class was 95,689.16 ha annual soil loss of 1.44 Mt/yr, severe erosion class was 3,90,953.6 ha annual soil loss of 11.73 Mt/yr, very severe erosion class was 1,86,843.2 ha annual soil loss of 11.21 Mt/yr and extremely severe erosion class was 1,18,677.4 ha annual soil loss of 11.87 Mt/yr. The annual loss of soil has been estimated as nearly about 34.81 million tonnes every year (Table 4.13) for Ratnagiri district.

4.5 Estimation of conservation practice factor (P)

The soil conservation need was estimated as the protection factor (P) when lands are not under any conservation programmes. The average rate of erosion covers both the cultivated and uncultivated parts of the crop and fallow period cycle, but the soil conservation measures described only applied and maintained in the cultivated part of the cycle. For Ratnagiri district different crop and fallow cycles of 4 yrs to 10 yrs periods were tested to reduce soil loss below tolerable limit and get maximum crop years. Hence, by using accurate crop and fallow period cycle, the conservation practice factor were obtained for nine tehsils of Ratnagiri district.

Thus, out of 4 yrs to 10 yrs crop cycles tested, 7 years crop cycle (Table 4.14) gave maximum crop year and minimum conservation practice factor to keep soil loss in tolerable limit. The total soil loss over 7 years crop cycle was 79 t ha^{-1}. The soil loss reduction were estimated for all tehsils of Ratnagiri district, e.g. required soil loss reduction for Mandangad tehsil of Ratnagiri district was 12.85 t/ha (79-66.15 t/ha) (Table 4.15). The total soil loss over 4 years was 67 t ha^{-1} (12+18+25+12) excluding fallow years from seven year crop cycle. Therefore, the estimated conservation practice factor (P) was 0.19 (12.85/67) (Table 4.15) for Mandangad tehsil of Ratnagiri district.

Thus, conservation practice factor (P) were calculated for all tehsils of Ratnagiri district (Table 4.15) was in the range of 0.19 – 0.22. The estimated P factors for Mandangad, Chiplun, Guhagar, Sangmeshwar, Khed, Ratnagiri, Lanja, Dapoli and Rajapur were 0.19, 0.19, 0.22, 0.22, 0.21, 0.21, 0.21, 0.21, and 0.20, respectively (Fig. 4.9). The average conservation practice factor (P) for Ratnagiri district was 0.21.

Table 4.14. Soil loss values over 7 years (for moderately deep soils)

Year	Land use	Soil loss (t/ha)	
		Annual	Total

1	Fallow	4	4
2	Crop-1st year	12	12
3	Crop-2nd year	18	18
4	Crop-3rd year	25	25
5-6	Fallow	4	8
7	Crop-1st year	12	12
Total soil loss over 7 years			79

(Source: Kassam *et al*. 1992)

Table 4.15. Estimation of tolerable soil loss rate (over 7 years) and conservation need (P factor) of Ratnagiri district (for moderately deep soils)

Tehsils	Tolerable rate of soil loss (t/ha)	Soil loss Reduction (t/ha)	Cons. Need (P factor)
Mandangad	66.15	12.85	0.19
Chiplun	66.15	12.85	0.19
Guhagar	64.05	14.95	0.22
Sangmeshwar	64.05	14.95	0.22
Khed	64.61	14.39	0.21
Ratnagiri	64.61	14.39	0.21
Lanja	64.61	14.39	0.21
Dapoli	64.61	14.39	0.21
Rajapur	65.66	13.34	0.20
		Average	**0.21**

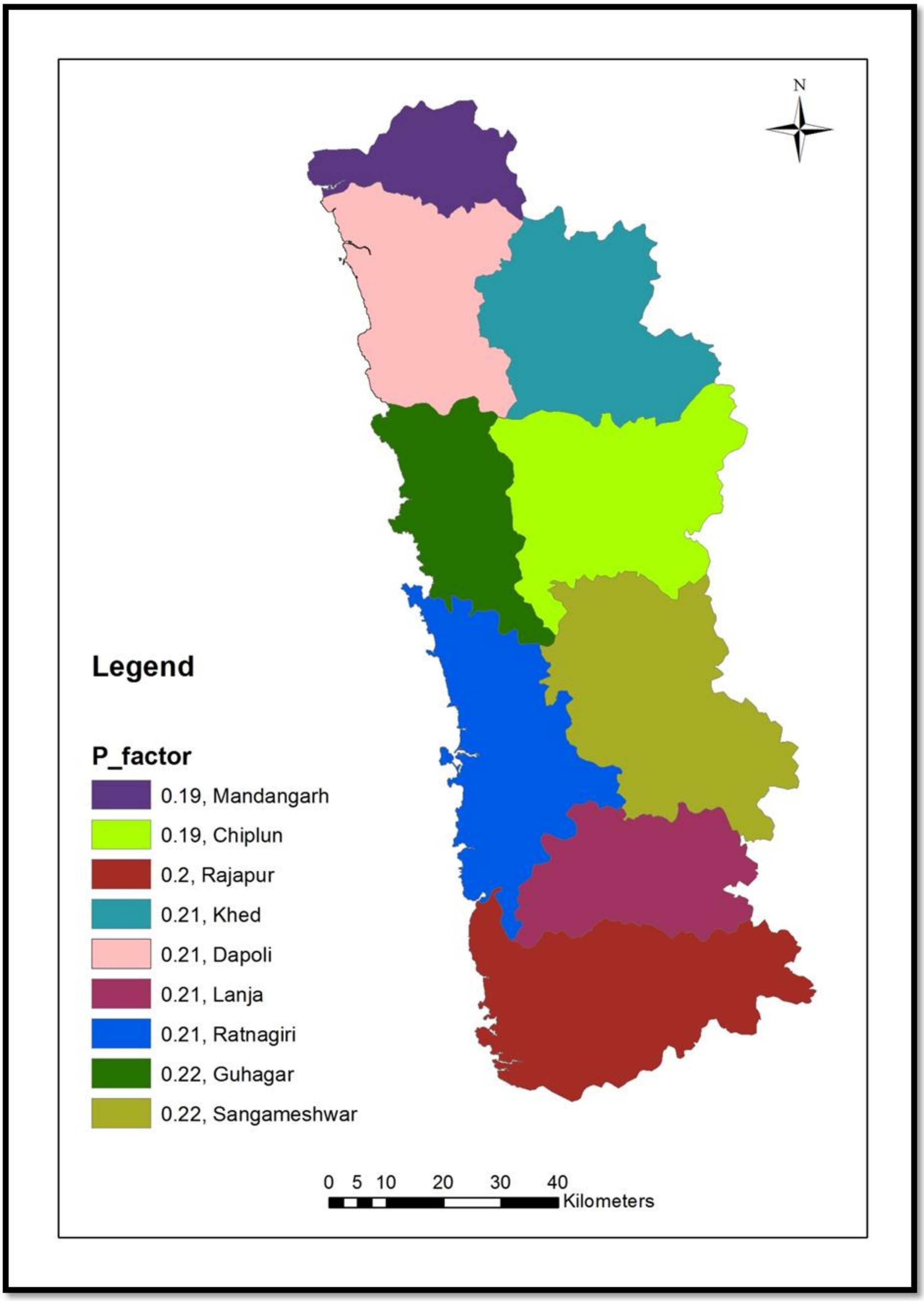

Fig. 4.9 Conservation practice factor (P) map of different tehsils of Ratnagiri district

4.6 Estimation of Average Annual Soil Loss after Conservation Measures

All the layers viz. R, K, LS, C and P (after conservation measures) were generated in ArcGIS and were overlaid to obtained the product, which gives annual soil loss (A) for the study area. Average annual soil loss for study area was calculated 43.61 t/ha/year (Fig.4.8) before soil and water conservation measures. Annual soil loss was calculated for study area after recommendation of soil and water conservation measures. Annual soil loss for study area after soil and water conservation measures was calculated as 9.31 t/ha/year (Fig. 4.10).

Soil Classification of micro watershed was done into six classes as slight, moderate, high, very high, severe, and very severe as per criteria given by Singh *et al.* (1992).

Table 4.16. Area under different classes of soil erosion after conservation measures for Ratnagiri district

Soil erosion class	Soil loss (t/ha/yr)	Area (ha)	Percent area
Slight	0-5	219329.6	26.19
Moderate	5-10	488462.3	58.32
Moderately severe	10-20	20118.44	2.40
Severe	20-40	109502	13.07
Very severe	40-80	100.7367	0.01

Due to recommendation of soil and water conservation measures soil loss 9.31 (t/ha/yr) will be expected to reduce from the study area. About 58.32% area will be expected to come under moderate erosion class, 26.19% area was under slight erosion class, 13.07% area under severe erosion class, 2.40% area was under moderately severe erosion class, and 0.01% area under very severe erosion class (Table 4.16). Tehsils wise area under different classes of soil erosion after adoption of conservation measures of Ratnagiri district as shown in Table 4.17.

Table 4.17. Tehsils wise Area under different classes of soil erosion after adoption of conservation measures of Ratnagiri district

Area under each class (ha)					
Soil erosion class (t/ha/yr) / Tehsil	Slight (0-5)	Moderate (5-10)	Moderately severe (10-20)	Severe (20-40)	Very severe (40-80)
Chiplun	36469.3	57382.73	7108.09	10272.12	-
Dapoli	30739.66	46365.22	135.05	13077.38	-
Guhagar	22911.55	35470.99	305.26	10170.58	-
Khed	30406.8	51748.78	736.34	18827.39	2.85
Lanja	14868.63	49240.1	1958.448	9077.465	23.57
Mandangad	17656.5	17929.85	1558.95	6624.35	-
Rajapur	27612.16	81205.15	682.013	14696.45	12.86
Ratnagiri	18518.27	65940.41	1648	10132.44	-
Sangameshwar	20102.64	83113.83	5983.75	16611.6	61.45

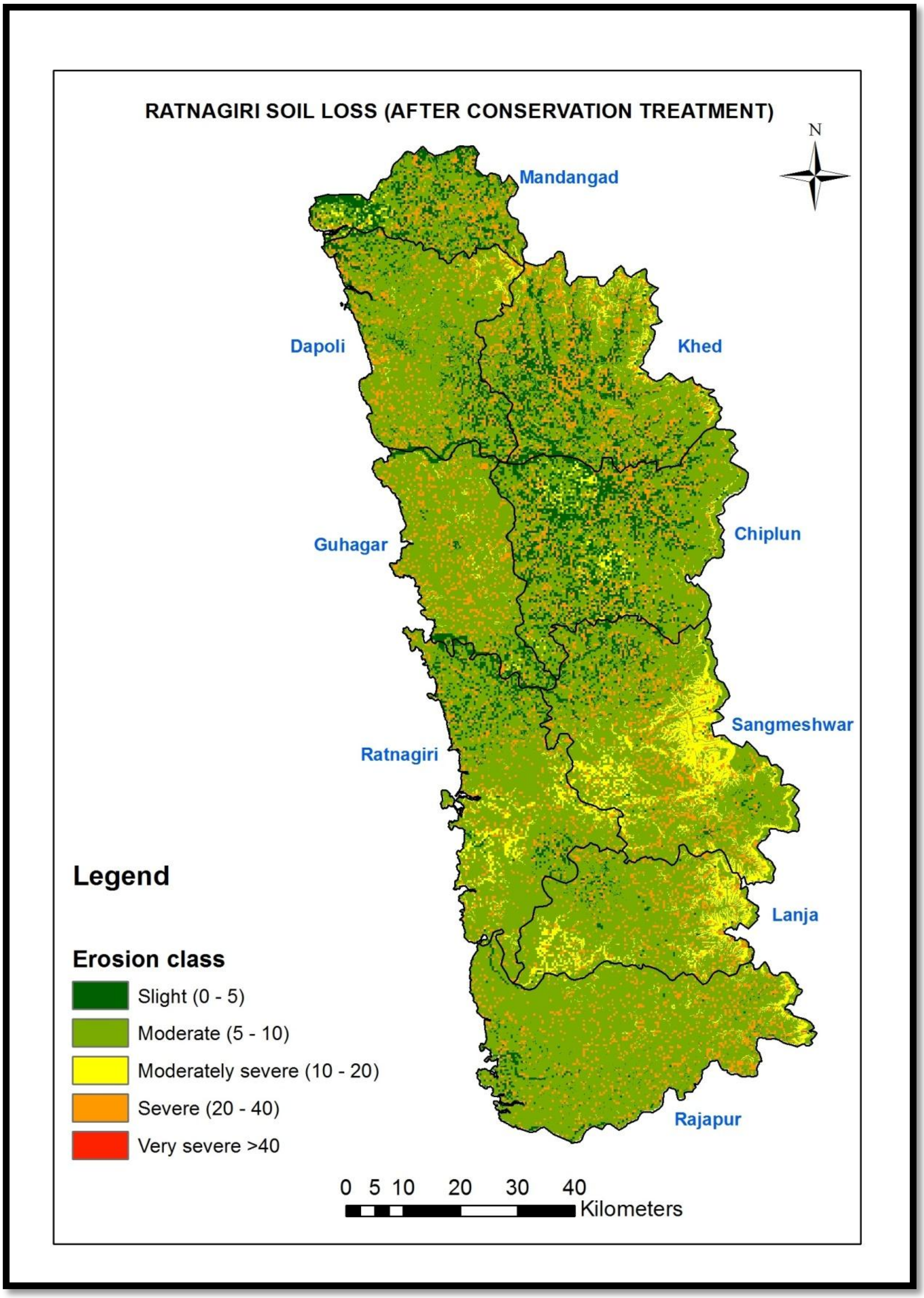

Fig 4.10: Average annual soil loss map of Ratnagiri district after conservation measures

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LIST OF ABBREVATIONS AND SYMBOLS

Abbreviations	**Description**
<	Less than
>	Greater than
%	Per cent
A	Annual soil loss
bt	Billion tonne
C	Crop management factor
CAET	College of Agricultural Engineering and Technology
Cm	Centimetre
DEM	Digital elevation model
E	East
EI_{30}	Erosivity index
Equ.	Equation
et al.	And others
etc.	Etcetera
FAO	Food and Agricultural Organization
Fig.	Figure
g	Gram
GIS	Geographic Information System
GPS	Global Positioning System
ha	Hectares
hr	Hour
i. e.	That is
IPCC	Inter Governmental Panel on Climate Change
IDW	Inverse Distance Weight
IRS	Indian Remote Sensing
K	Soil erodibility factor
kg	Kilo gram
km	Kilo meter
km^2	Square kilo meter
L	Slope length factor
LANDSAT ETM +	Landsat Enhanced Thematic Mapper plus

LISS	Linear Imaging Self Scanner
LS	Topographic factor
LU/LC	Land use/ land cover
LUP	Land use planning
M	Million
m	Meter
m^3	Cubic meter
Mha	Million hectare
MJ	Mega Joule
mm	Millimetre
mm/hr	Millimetre per hour
N	North
NBSS	National Bureau of Soil Survey
No.	Number
OC	Organic carbon
OM	Organic matter
P	Conservation practice factor
R	Rainfall erosivity factor
RS	Remote sensing
S	Slope steepness factor
SCS	Soil Conservation Service
SOI	Survey of India
SPAW	Soil-Plant-Air-Water
SRTM	Satellite Radar Topography Mission
T	Tonne
USDA	United States Department of Agriculture
USLE	Universal soil loss equation
viz.	Namely
yr	Year

ABSTRACT

"SOIL EROSION AND CROP PRODUCTIVITY MODEL FOR RATNAGIRI DISTRICT"

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Soil degradation has reached alarming proportions in many parts of the world, especially in the tropics and sub-tropics because of its uneconomic overexploitation. Also soil degradation is one of the most critical environmental hazards of recent times. A large area suffers from soil erosion, which in turn, reduces productivity. For protection of land and to meet the increasing demand of food, it is necessary to understand soil formation and erosion process. This kind of study is very essential in Konkan region of Maharashtra due to extreme weather conditions and huge loss of soil through runoff. Therefore, there is need to study estimation of actual soil loss and tolerable soil loss which helps to convert topsoil loss into productivity loss.

Ratnagiri district of Konkan is located between $15^0$40' and 18°5' N latitude and $73^0$5' and $73^0$55' E longitude. The total geographical area of Ratnagiri district is 8,461 sq. km. with average annual rainfall of 3,591mm, which comprises of nine tehsils. Universal Soil Loss Equation (USLE) model was used to predict soil loss from the Ratnagiri district of Maharashtra, India. Remote Sensing (RS) and Geographic Information System (GIS) techniques were applied to prepare various layers of USLE parameters which interactively estimate soil erosion from Ratnagiri district.

Average annual soil loss was estimated with the help of average annual R factor obtained from 28 years rainfall data, K, LS, C and P. The average annual erosivity of Ratnagiri district was 10,195.48 MJ-mm/ha-hr-yr. Soil erodibility factor for different villages of Ratnagiri district were found in the range of 0.0346 to 0.0636 t-ha-hr/ha-MJ-mm. The values of LS factor for study area was found in the range of 1.953 to 4.393. Crop management factor (C) values for study area were ranging from 0.024 to 0.12. Conservation

practice factor was considered 1 before recommendation of soil and water conservation measures and used to estimate soil loss. Average annual soil loss from the Ratnagiri district was 43.61 t/ha/yr before recommendation of soil and water conservation measures.

It was observed that about 57.62 % area was under severe erosion class, 24.24% area was under very severe erosion class and 14.17% area was under extremely severe erosion class of Ratnagiri district without soil and water conservation treatments. Thus, more than 80% of area from Ratnagiri district comes under severe (20-40 t/ha/yr) to extremely severe (>80 t/ha/yr) erosion classes. This proves the high need of soil and water conservation measures in the watershed for the sustainable management of natural resources.

Tolerable soil loss of Ratnagiri district was estimated based on imperial relations with the help of bulk density, depth of soil and other data. Estimated average tolerable soil loss and conservation practice factor (P) values for Ratnagiri district are 9.45 t/ha/yr (for moderately deep soil) and 0.21, respectively. Average annual soil loss from study area would reduce to 9.31 t/ha/yr after adoption of recommended soil and water conservation measures and following 7 years of crop cycle. It was observed that about 58.32% area is expected to come under moderate erosion class, 26.19% area under slight erosion class, 13.07% area under severe erosion class, 2.40% area under moderately severe erosion class, and 0.01% area under very severe erosion class after adoption of soil and water conservation measures. Thus, soil erosion and crop productivity model can be effectively used for planning of soil and water conservation measures in Ratnagiri district.

V. SUMMARY AND CONCLUSIONS

Soil erosion is a disastrous environmental problem throughout the world. Erosion is a slow insidious problem that is continuous. Indeed, 1mm of soil, easily lost in one rain or wind storm, is so minute that its loss goes unnoticed by the farmer and others. Yet this loss of soil over a hectare of cropland amounts to about 15 t/ha. Replenishing this amount of soil under agricultural conditions requires approximately 20 years, meanwhile the lost soil is not available to support crops. Along with the loss of soil is the loss of water, nutrients, soil organic matter, and soil biota. The soil system is severely harmed when soil erosion is allowed to occur.

The loss of soil from land surfaces by erosion is widespread and reduces the productivity of all natural ecosystems as well as agricultural, forest, and pasture ecosystems (Lal and Stewart, 1990).

The rates of soil erosion that exceed the generation of new topsoil are a dynamic process which leads to decline in the soil productivity, low agricultural yield and income. The balance between soil-forming and depleting processes is of utmost importance for attaining long-term sustainability in any production system (Kumar and Pani, 2013).

Concurrently with the growing human population, soil erosion, water availability, climate change due to fossil fuel consumption, coastal marine bodies of water, and loss of biodiversity rank as the prime environmental problems throughout the world. With the world population now over seven billion and expected to reach 9.3 billion by 2050, more food will be needed (UN. World Population Prospects, 2011). Consider at present that more than 99.7% of human food (calories) comes from the land (FAO, 2001), while less than 0.3% comes from the marine and aquatic ecosystems. Maintaining and augmenting the world food-supply basically depends on the productivity and quality of all agricultural soils. Worldwide, soil erosion continues unabated while the human population continues to increase rapidly and 66% of the world population is now malnourished (WHO, 2000). If soil conservation is ignored and population control is ignored, more malnourished people and more deaths will occur.

Overall, soil is being lost from agricultural areas 10 to 40 times faster than the rate of soil formation imperiling humanity's food security. Tolerable soil loss is a concept developed in the 20th century and it is useful to judge if a soil has potential risk of erosion, productivity loss and off-site damages. Quantifying the acceptable soil loss without affecting crop productivity is a major challenge for researchers, planners, conservationists and environmentalists. This kind of study is very essential in Konkan region of Maharashtra due to extreme weather conditions and huge loss of soil through runoff. Ratnagiri is part of Western Ghats which comes under one of 34 world biodiversity hotspots (Myers *et al*., 2000 and Chitale *et al*., 2015). Ratnagiri district is ecologically sensitive region where natural resources need to be protected with maximum care.

Assessment of soil erosion is an expensive and intensively long exercise. A number of parametric models have been developed to forecast soil erosion at drainage basins. The RS and GIS techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage. Therefore, present study was undertaken to access the soil erosion and tolerable soil loss and conservation practice factor of Ratnagiri district.

Ratnagiri is a coastal district of Maharashtra state, situated in the western coast of India. Ratnagiri district is located between $15^0$40' and 18°5' N latitude and $73^0$5' and $73^0$55' E longitude. The total geographical area of Ratnagiri district is 8,461 sq. km. Average annual rainfall of Ratnagiri district is 3,591mm. It comprises of nine tehsils, namely Mandngad, Dapoli, Khed, Chiplun, Guhagar, Sangmeshwar, Ratnagiri, Lanja and Rajapur.

Universal soil loss equation (USLE) model has been widely used for estimation of soil loss from the watershed. The parameters of these models were determined by using GIS technologies and from the data collected from various sources.

Daily rainfall data from 1984 to 2011 of five stations in the study area were used to compute annual rainfall erosivity (R factor). R factor values were calculated using relationship between the daily rainfall and erosivity index of Wakawali region by developing regression equation. The average annual erosivity for Hedvi, Karak, Poynar, Dapoli and Wakawali stations were 10,001.93, 10,837.42, 9,734.62, 10,285.58 and 10,117.86 respectively.

The different soil parameters such as sand, silt, clay and organic carbon were used from previous work (Thawakar, 2014). Soil erodibility factor were calculated for 45 villages of Ratnagiri district. Soil erodibility factor for different villages of Ratnagiri district were found in the range of 0.0346 to 0.0636.

Digital elevation model (DEM) of the study area was prepared using SRTM data. A slope map was created from the DEM based on the slope map, slope length (L) and slope gradient (S) maps and finally a layer of LS factor was generated. The values of LS factor for study area was found in the range of 1.953 to 4.393.

LANDSAT images used for preparation of land use land cover map. The land use/cover classification of the study area was carried out using supervised classification (maximum likelihood classification). Classification was carried out for five land use classes: forest, agricultural land, waterbody, barren land and urban area. Crop management factor (C) values for study area were ranging from 0.024 to 0.12.

P factor value was considered as 1 for Ratnagiri as it was assumed as an untreated data. Using P value as 1, conservation practice factor (P) map was prepared and used in USLE to calculate soil erosion. Total soil loss from study area was estimated as 43.61 t/ha/yr. Highest percent of area was found under the severe soil erosion class of (46.67%), followed by very severe (22.31%), extremely severe (14.17%), moderately severe (11.42%), moderate (4.14%) and slight (1.30%) before recommendation of soil and water conservation measures. It showed that more than 80% of area comes under severe to extremely severe erosion class which was cause of concern.

The soil loss and crop productivity model were used to estimate the tolerable soil loss. It also used to convert topsoil loss into productivity loss to estimate soil conservation needs. Estimation of tolerable soil loss has been done (i) through value of yield loss that can be tolerated or (ii) the proportion of land (%) that can be allowed to make the depth of soil shallower at least by one soil depth class over a specified time period. Estimated average tolerable soil loss (t/ha/yr) for Ratnagiri district was 3.09 t/ha/yr for moderately shallow soil, 9.25 t/ha/yr for moderately deep soil, 15.42 t/ha/yr for deep soil and 18.50 t/ha/yr for very deep soil with low soil susceptibility (25%). Using this tolerable soil loss rate, the conservation need (P) factor for Ratnagiri district was calculated. The estimated P factors for Mandangad, Chiplun, Guhagar, Sangmeshwar, Khed, Ratnagiri, Lanja, Dapoli and Rajapur were 0.19, 0.19, 0.22, 0.22, 0.21, 0.21, 0.21, 0.21, and 0.20 respectively for Ratnagiri tehsils. The average conservation practice factor (P) for Ratnagiri district was 0.21.

Total soil loss from study area after adoption of recommended soil and water conservation measures is expected to be 9.31 t/ha/yr. About 58.32% area is expected to come under moderate erosion class, 26.19% area under slight erosion class, 13.07% area under severe erosion class, 2.40% area under moderately severe erosion class, and 0.01% area under very severe erosion class.

CONCLUSIONS:

The salient conclusions drawn from the present study are as follows:

1. The average annual erosivity factor for Ratnagiri district was 10195.48 MJ-mm/ha-hr-yr.

2. Soil erodibility factor for different locations of Ratnagiri district was found in the range of 0.0346 to 0.0636 t-ha-hr/ha-MJ-mm.
3. The value of LS- factor for study area was found in the range of 1.95 to 4.39.
4. Crop management factor value for Ratnagiri district was ranging from 0.024 to 0.12.
5. Estimated soil loss from Ratnagiri district using USLE was 43.61 t/ha/yr before soil and water conservation measures.
6. It was observed that about 1.30% area was under slight erosion class, 1.46% area was under moderate erosion class, 1.21% area was under moderately severe erosion class, 57.62 % area was under severe erosion class, 24.24% area was under very severe erosion class and 14.17% area was under extremely severe erosion class of Ratnagiri district before soil and water conservation measures.
7. More than 80% of area from Ratnagiri district comes under severe (20-40 t/ha/yr) to extremely severe (>80 t/ha/yr) erosion classes.
8. Estimated average tolerable soil loss for Ratnagiri district was 9.45 t/ha/yr for moderately deep soil.
9. The estimated average conservation practice factor (P) was 0.21 for Ratnagiri district.
10. Estimated soil loss from Ratnagiri district using USLE is expected to be 9.31 t/ha/yr after adoption of soil and water conservation measures.
11. It was observed that about 58.32% area is expected to come under moderate erosion class, 26.19% area under slight erosion class, 13.07% area under severe erosion class, 2.40% area under moderately severe erosion class, and 0.01% area under very severe erosion class after adoption of soil and water conservation measures.

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