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Climatic water balance, probable rainfall, rice crop water requirements and cold periods in AER 12.0 in India

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Abstract

In this study an analysis was made on spatial variation of climatic water balance, (water surplus, actual evapotranspiration), probabilistic monthly monsoon rainfall and mapping of cold periods in agro-ecological region (AER) 12.0 of India using GIS and models. Since, rice is the dominant crop of the region, crop water requirements of rice was also spatially analyzed in different agro-ecological subregions (AESRs) of the AER 12.0 using CROPWAT 4.0 model and GIS. Study found that as per climatic water balance, large to moderate water surplus (520–70 mm) was available in AESR 12.1. The rainfall surplus of 220–370 mm was computed in AESR 12.2 and 370–520 mm in AESR 12.3 mm. Since winter rainfall is meagre and erratic, this amount of rainfall may be harvested and utilized for providing supplemental irrigation to winter crops or during dry spell of rainy season crops. Study also reveals that at 80% probability level (highly assured) in first month of southwest monsoon (June) 98–156 mm rainfall occurs in AESR 12.1, 103–144 mm in AESR 12.2 and 93–132 mm in AESR 12.3. These amounts of rainfall are sufficient to prepare land and sowing of direct seeded crops like maize, groundnut, blackgram, greengram, pigeonpea, cowpea, etc. that may be done from 24th standard week onwards (11th–7th June) after onset of southwest monsoon in the region. Based on existence of favorable temperature, among different AESRs, cold requiring crops may be tried in the districts of AER 12.1, but before cultivation of these crops, economic feasibility should be properly assessed. In normal rainfall year 450–550 mm, 600–720 mm and 775–875 mm crop water requirement was computed using CROPWAT

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4.0 model for autumn rice, winter rice and summer rice, respectively in different AESRs of AER 12.0.

Keywords: Agro-ecological region; Climatic water balance; Water requirement; GIS; Rice

1. Introduction

Any pragmatic crop planning needs a thorough understanding of the climate and in particular, the rainfall (its variability in the amount, distribution and probability of occurrence), evaporative demand and atmospheric temperature. The rainfall and evapotranspiration ultimately determine water balance, crop water and irrigation requirements of different crops of the region. Studies of such climatic parameters are thus helpful in defining risk levels in arable agriculture, characterizing length of growing period and cropping system in different agro-ecological regions (AER), especially in rainfed area. The AER 12.0 of India (falls under eastern part of India, Fig. 1) receives higher annual average rainfall, varies from 900 to 2000 mm, but due to lack of appropriate water and soil management, the region has one of the lowest agricultural productivity of the country.

Interfacing output of models with geographic information system (GIS) increases the scope of applicability of the models for regional level planning and policy analysis

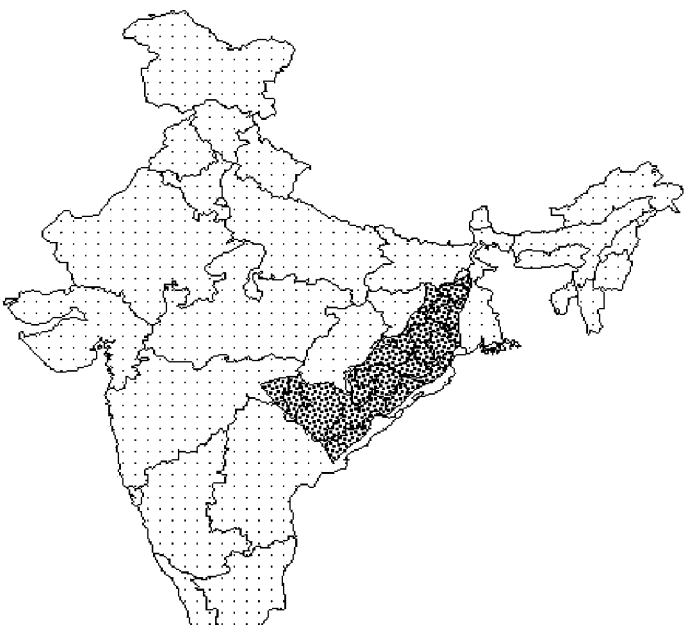

Fig. 1. Location of agro-ecological region (AER) 12.0 of India.

(Hartkamp et al., 1999; Heinemann and Hoogenboom, 2000). GIS is a powerful computer assisted tool at the disposition of policy and decision makers for acquisition, storage, analysis and display voluminous data. Decision makers usually need information at broader spatial scales at country, watershed or state levels. Several researchers have interfaced crop model output to GIS for analyzing productivity of water balance parameters at regional scale in different parts of the world (Beinorth et al., 1998; Hansen and Jones, 2000; Lal et al., 1993 and Smith, 2000). In this study output of climatic water balance and CROPWAT 4.0 model was mapped using ARCINFO and ARCVIEW GIS tools (ESRI, 1998).

Since rice is the dominant crop of the region, crop water and irrigation requirements of rice during different seasons (autumn, winter and summer rice) were computed using CROPWAT 4.0 model and were geospatially mapped. Probabilistic monthly rainfall during southwest monsoon season was also computed to predict rainfall at highly assured level. Generally in AER 12.0 of India atmospheric temperature is not a constraint for cultivation of crops during rainy season but rapid rise of temperature from February limits cultivation of many cold-requiring crops like *Brassica*, wheat, potato, chickpea, etc., during post-rainy season. Hence, in this study favorable thermal zone for growing cold requiring winter crops were also demarcated using GIS tools. Therefore, main objective of the study was to determine spatial variation of climatic water balance, probabilistic rainfall, water requirements of rice and to identify areas that are potential for growing cold requiring crops like wheat, *Brassica*, potato, chickpea, etc., in AER 12.0.

2. Materials and methods

The AER 12.0 (Fig. 2), popularly known as eastern (Chhotanagpur) plateau, eastern ghats and hot subhumid eco-region of India which comprises of three AESRs (Fig. 3), namely 12.1 (parts of Eastern Ghats highlands of Orissa, Maharastra, Baster region of Madhya Pradesh and non-coastal part of Andhra Pradesh), 12.2 (south eastern windward side of western high land of Orissa and north-eastern parts of Andhra Pradesh) and 12.3 (Chhotonagpur plateau of Bihar, parts of eastern ghats of Orissa and Western parts of West Bengal). Based on homogeneity in soil characteristics, and length of the growing periods the AER 12.0 was divided into three agro-ecological subregions viz., AESR 12.1, AESR 12.2 and AESR 12.3 (Velayutham et al., 1999).

In AER 12.0, there is a large spatial variation of meteorological parameters, which influence climatic water balance (potential evapotranspiration, actual evapotranspiration, moisture surplus, length of growing period), crop water requirement (CWR) and growing of thermal sensitive crops.

2.1. Soil Characteristics of the region

Soils of AESR 12.1: The Ekma series and Chougel series comprising Typic Haplustalfs and Typic Plinthustalfs, respectively are the dominant soil series in the area. Ekma soils are fine loamy, mildly acidic to neutral with high base saturation. The surface texture varies from loamy sand to sandy loam abruptly underlined by heavy subsurface. The surface

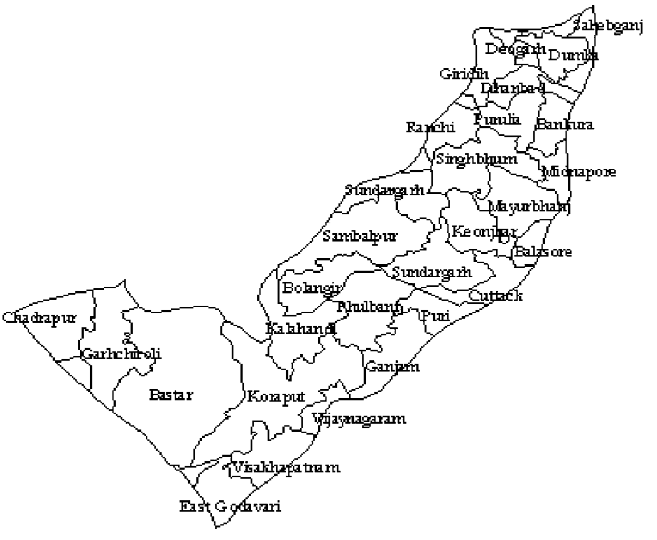

Fig. 2. District map of AER 12.0.

texture of the Chougel series varies from sandy clay to clay loam and the clay content increases with depth. The available water capacity varies from 100 to 125 mm/m.

Soils of ARSR 12.2: The dominant two soil series of this zone are Bhubaneswar (Typic Haplustalfs) and Parichhal (Aquic Haplustalf) series. Bhubaneswar series are fine loamy, acidic with low base saturation while Parichhal series are clayey, mildly acidic to neutral with medium base saturation. The surface texture varies from loamy sand to sandy loam and the clay content increases in subsurface horizon with subsequent decrease in the

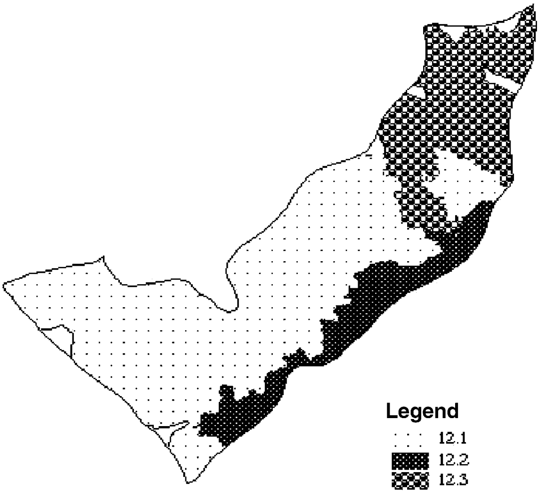

Fig. 3. Agro-ecological subregion (AESR) of AER 12.0.

subsoil. The available water capacity is relatively low and varies between 100 and 120 mm/m. The Parichhal sand clay pedon found in valleys and in shallow depressions of undulating terrain. The surface texture varies from sandy clay to clay. The available water capacity varies between 125 and 150 mm/m.

Soils of AESR 12.3: The Ultic Paleustalf (Pusaro loam) and Typic Ochraqualf (Hatiapather silt loam) are the dominant soil groups in the region. The Pusaro loam are strong brown to yellowish red and have sandy loam to loam surface texture. The CEC of these soils is low with low base saturation. The available water capacity varies between 100 and 125 mm/m. On the other hand, the Hatiapather soil series have grayish brown, strongly acid silt loam to loam surface soils, acidic with moderate CEC and moderately high base saturation. The available water holding capacity is moderate (150 mm/m).

Different meteorological parameters like mean maximum air temperature, minimum air temperature, relative humidity, wind velocity, rainfall of different districts of AER 12.0 of India were collected from different sources (Regional Center of Indian Meteorological Department, Bhubaneswar; Indian Meteorological Department, Pune; Revenue Department, Government of Orissa, India). The monthly climatic water balance was computed using book keeping procedure of Thornthwaite and Mather (1957) based on rainfall and potential evapotranspiration (PET) values, considering average available water holding capacity of soils as 110, 125 and 125 mm/m in AESR 12.1, AESR 12.2 and AESR 12.3, respectively. The number of days moisture availability index (AET/PET) exceeded 0.5, considered as length of the growing period (LGP) for the region.

The reference evapotranspiration was estimated using FAO Penman–Monteith (1998) equations, which was recommended by FAO, Rome as standard method (Allen et al., 1998).

$$\mathrm{ET}_0 = \frac{0.408\Delta(R_\mathrm{n} - G) + \delta 900/(T + 273)u_2(e_\mathrm{s} - e_\mathrm{a})}{\Delta + \delta(1 + 0.34u_2)}$$

ET_0 is the reference crop evapotranspiration (mm day^{-1}), R_n the net radiation at the crop surface (MJ m^{-2} day^{-1}), G the soil heat flux density (MJ m^{-2} day^{-1}), T the mean daily air temperature at 2 m height (°C), u_2 the wind speed at 2 m height (ms^{-1}), e_s the saturation vapour pressure (KPa), e_a the actual vapour pressure (KPa), Δ the slope of vapour pressure crop (KPa °C^{-1}), δ the psychometric constant (KPa °C^{-1}).

The crop water requirement (ET_c) of rice was computed by multiplying the crop coefficient (K_c) with ET_0 at different growth stages (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979). The crop coefficient of rice was taken from locally available values (Tripathy, 2004).

The monthly probabilistic rainfall was estimated by extreme value distribution type-1, the probability density function $f(x)$ and distribution function $F(x)$ are given as

$$f(x) = \frac{[\exp - (x - u)/\alpha - \exp\{-(x - u)/\alpha\}]}{\alpha}$$

and

$$F(x) = \exp\left[-\exp\left\{-\frac{x - u}{\alpha}\right\}\right], \qquad -\alpha < x < \alpha, \qquad -\alpha < u < \alpha, \quad \alpha > 0$$

where α and u are the shape and location parameters of the distribution, respectively.

In term of the reduced variate $Y = [(x - u)/\alpha]$,

$$F(x) = \exp[-\exp(-Y)]$$

The method of moment estimation of the parameters have been used for this study to fit extreme value distribution are as follows:

$$\alpha = \left(\frac{\sqrt{6}}{\pi}\right)\left[\frac{\sum(x-\bar{x})^2}{N-1}\right]^{1/2}, \qquad u = x - 0.577216\alpha$$

2.2. GIS methodologies

The district map of AER 12.0 was extracted from agro-ecological regions of India map, prepared by National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur and was scanned. The scanned map was then on-screen digitized using R_2V software and ARCINFO GIS coverage was prepared. This digitized map i.e. vector layer of district boundary was then cleaned and checked for errors like dangles and pseudonodes, etc. After removing these errors, the layer was then built for topology using commands in the ARC/INFO package. The map was projected using ‘polyconic projection’ and ‘Everest’ geoid system. The output of different model parameters was then linked with district polygon map as attributes and classified into number of classes as per criteria, using Arc View GIS (ESRI, 1998).

3. Results and discussion

3.1. Seasonal distribution of rainfall and variability of monthly rainfall

Average seasonal distribution of in different AESRs are presented in Table 1. About 56–188 mm in AESR 12.1, 76–184 mm in AESR 12.2 and 65–184 mm in AESR 12.3 rainfall occurs during pre-monsoon period (March–May) which would be useful for summer ploughing to make the land ready for final land preparation in rainfed upland and direct sowing of rainfed lowland rice especially in medium deep and deep water rice ecology.

The average rainfall during the monsoon months (June–September) were 608–1580 mm (55.9–88.9%) in AESR 12.1, 509–1187 mm (52.2–76.1%) in AESR 12.2 and 942–1204 mm (75.5–85.2%) in AESR 12.3 but major part of this rain is generally lost through runoff which can be utilized for providing supplementary irrigation to second crops. It can be utilized as life saving irrigation particularly in the years when rain during post-monsoon season is low or also for growing short duration pulses like greengram, blackgram and oilseeds like mustard, linseed and groundnut in rainfed lowlands after rice during winter/summer season. A very good amount of rainfall (81–274 mm in AESR 12.1, 228–459 mm in AESR 12.2 and 84–193 mm in AESR 12.3) is also received during post-monsoon season of October–November which will helpful for rainfed lowland rice because most of the long duration photo-sensitive rice varieties viz., Gayatri, Savitri, Durga and Sarala, etc., grown in the region are at flowering stage during late October or early November. Any deficit of

Table 1
Seasonal distribution of rainfall (mm) in AER 12.0

District	Pre-monsoon (March + April + May)	Monsoon (June + July + August + September)	Post-monsoon (October + November)	Winter (December + January + February)	Total
AESR 12.1					
East Godavari	74 (6.8%)	608 (55.9%)	274 (25.2%)	32 (2.9%)	1088
Baster	134 (8.7%)	1237 (80.5%)	140 (9.1%)	24 (1.5%)	1355
Chandarpur	63 (4.2%)	1300 (88.1%)	81 (5.4%)	32 (2.1%)	1474
Garhchiroli	56 (3.5%)	1400 (88.9%)	85 (5.4%)	34 (2.1%)	1574
Balasore	78 (4.9%)	1397 (87.9%)	94 (5.9%)	19 (1.2%)	1588
Dhenkanal	210 (13.5%)	1151 (74.1%)	138 (8.8%)	53 (3.4%)	1552
Kalahandi	119 (7.6%)	1227 (78.1%)	131 (8.4%)	21 (1.3%)	1559
Koraput	136 (8.2%)	1370 (81.9%)	153 (9.1%)	12 (0.7%)	1671
Mayurbhanj	82 (6.0%)	863 (63.4%)	273 (20.1%)	42 (3.1%)	1361
Phulbani	188 (13.2%)	989 (69.4%)	202 (21.4%)	46 (2.6%)	1425
Sambalpur	69 (3.4%)	1580 (89.5%)	78 (4.4%)	46 (2.6%)	1764
Sundergarh	128 (8.1%)	1283 (81.7%)	103 (81.7%)	56 (3.5%)	1570
				Mean of the subregion:	1496.7 mm
AESR 12.2					
Visakhapatnam	76 (7.8%)	509 (52.2%)	350 (35.8%)	40 (4.1%)	975
Vizianagaram	109 (9.3%)	806 (68.6%)	228 (19.4%)	31 (2.6%)	1174
Balasore	184 (10.9%)	1174 (69.5%)	275 (16.2%)	57 (3.3%)	1690
Cuttack	119 (7.6%)	1187 (76.1%)	209 (13.4%)	44 (2.8%)	1559
Ganjam	88 (6.7%)	719 (54.8%)	459 (35.0%)	45 (3.4%)	1311
Puri	89 (6.1%)	997 (69.2%)	317 (22.0%)	37 (2.5%)	1440
				Mean of the subregion:	1358.1 mm
AESR 12.3					
Birbhum	159 (11.4%)	1056 (75.9%)	134 (9.6%)	41 (2.9%)	1391
Bankura	99 (7.2%)	1101 (80.1%)	129 (9.3%)	44 (3.2%)	1373
Purulia	90 (6.8%)	1108 (84.7%)	84 (6.4%)	25 (1.9%)	1307
Midnapore	184 (11.3%)	1204 (74.0%)	193 (11.8%)	46 (2.8%)	1327
Dhanbad	73 (6.1%)	985 (85.2%)	99 (8.2%)	41 (3.4%)	1198
Ranchi	101 (6.9%)	1172 (80.1%)	112 (7.6%)	67 (4.5%)	1462
Giridih	65 (5.6%)	942 (82.2%)	92 (8.03%)	46 (4.1%)	1145

Table 1 (*Continued*)

District	Pre-monsoon (March + April + May)	Monsoon (June + July + August + September)	Post-monsoon (October + November)	Winter (December + January + February)	Total
Sahebganj	120 (9.1%)	1039 (78.5%)	118 (8.4%)	38 (2.8%)	1316
Dumka	109 (7.8%)	1106 (79.5%)	131 (9.1%)	44 (3.1%)	1391
Deogarh	75 (6.1%)	1009 (81.2%)	113 (9.1%)	45 (3.6%)	1242
Singhbhum(east)	119 (8.5%)	1136 (81.6%)	93 (6.6%)	44 (3.1%)	1392
Singhbhum(west)	115 (8.1%)	1033 (78.6%)	120 (9.1%)	46 (3.5%)	1314
Keonjhar	162 (11.3%)	1075 (75.5%0	121 (8.5%)	64 (4.5%)	1422
				Mean of the subregion:	1329.2 mm

Values in parentheses indicates percentage of total annual rainfall.

rainfall during this period adversely affects the final yield of rainfed lowland rice. The winter rain is meager (0.72–3.5% in AESR 12.1, 2.5–4.1% in ARSR 12.2, 1.9–4.5% in AESR 12.3) and crops like pea, linseed, lathyrus, blackgram, safflower can be grown by utilizing the residual soil moisture in rainfed shallow lowlands.

The coefficient of variability of monthly rainfall was computed and results are presented in Table 2. Study reveals that among different months rainfall variability is less during monsoon months for all the ASERs of AER 12.0 of India. Among different months, rainfall was less variable in July and August. The summer and winter rainfall are meagre and highly variable. So growing of second crops during winter season after rainy season rice without supplementary irrigation would be risky.

3.2. Climatic water balance and length of growing period

The climatic water balance parameters viz., actual evapotranspiration (AET), moisture surplus and length of growing period (LGP) were computed using Thronthwaite and Mather's (1957) book keeping procedure, considering the average available water capacity of soils as 110 mm/m, 125 mm/m and 125 mm/m in AESR 12.1, AESR 12.2 and AESR 12.3, respectively. Study reveals that AET of the region ranged between 750 mm and 1150 mm in different districts and AESRs of the AER 12.0 (Fig. 4). The AET of the AER 12.0 was classified into four classes viz., 750–850, 850–950, 950–1050 and 1050–1150 mm and study revealed that in AESR 12.2 (which comprises of coastal Orissa and Andhra Pradesh), AET was higher than that of other region. Using ARCVIEW GIS tool, the whole region was classified into 5 water surplus zone (Fig. 5) and study found that large to moderate water surplus (500–600 mm) was available in AESR 12.1, rainfall surplus of 200–350 mm was computed in AESR 12.2 and 350–500 mm in AESR 12.3. Since winter

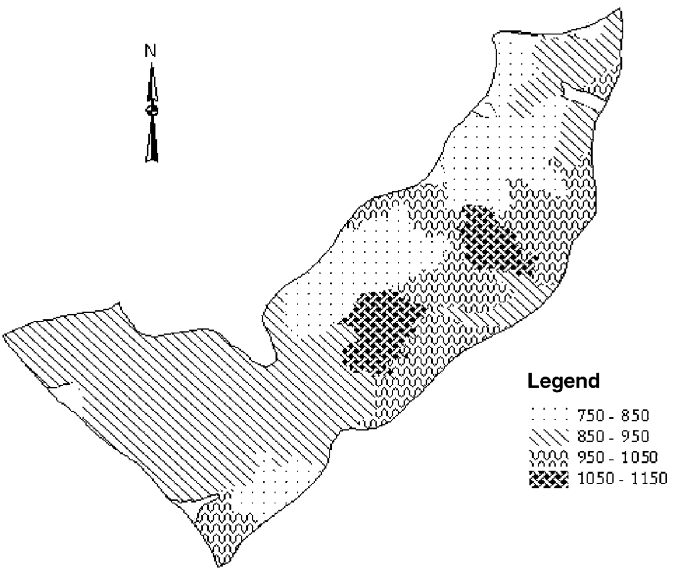

Fig. 4. Actual evapotranspiration (AET (mm)) in AER 12.0.

Table 2
Variability of monthly rainfall (%) in different districts of AER 12.0

Districts	January	February	March	April	May	June	July	August	September	October	November	December
AESR 12.1												
Dhenkanal	199	148	274	81	98	47	38	35	30	90	176	313
Phulbani	162	160	135	83	101	54	34	42	131	83	207	309
Kalahandi	212	157	189	83	98	50	33	35	47	109	162	335
Koraput	223	137	105	67	81	42	23	29	34	73	153	249
Mayurbhanj	213	147	104	73	64	41	28	33	44	96	199	233
Sambalpur	178	134	153	109	80	57	29	33	41	82	185	294
Sundergarh	182	145	177	91	78	47	43	30	41	80	188	299
Bolangir	243	139	142	89	107	56	30	39	50	114	213	391
Chandrapur	190	134	124	101	90	49	36	30	69	84	139	258
AESR 12.2												
Cuttack	208	124	141	94	103	43	33	31	36	79	168	249
Balasore	152	120	120	86	78	46	33	33	40	73	177	273
Ganjam	158	130	103	68	121	47	34	37	40	67	145	319
Puri	212	138	139	93	93	39	32	33	37	85	165	268
Visakhapatnam	210	147	104	70	90	40	33	30	35	85	149	234
AESR 12.3												
Keonjhar	118	145	131	92	56	44	23	28	34	87	172	330
Bankura	211	104	97	80	68	11	20	26	58	72	136	176
Purulia	199	111	107	87	66	18	23	24	68	98	119	198
Midnapore	160	93	96	52	46	23	18	23	39	78	16	208
Birbhum	178	112	97	65	44	30	20	25	45	76	117	186
Ranchi	198	125	109	86	68	19	24	24	73	99	117	176

Data source: Revenue Department, Cuttack; Regional Meteorological Centre, Bhubaneswar, and IMD, Pune.

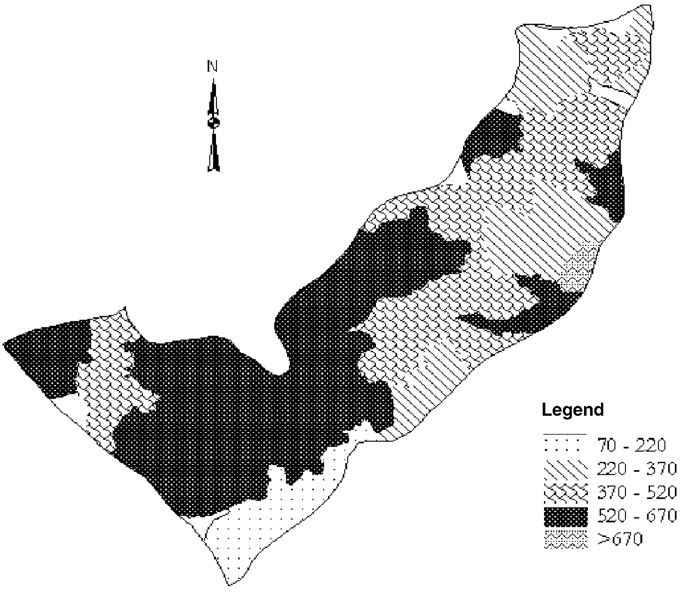

Fig. 5. Water surplus (mm) zone in AER 12.0.

rainfall (dry season) is meager and erratic, this amount of rainfall may be harvested and utilized for providing supplementary irrigation during dry season for growing short duration crops like greengram, blackgram, linseed, mustard, sunflower, safflower, pea etc. The length of the growing period in AESR 12.1 (LGP) ranged between 150 and 200 days started from 23rd standard weeks (4th–10th June) and ended in December. In the 12.2 subregion moisture availability period begun from end of June and continued up to December. The LGP ranged between 200 and 250 days in AESR 12.2 (Fig. 6), which occurred mainly in four humid months (July–October) and two moderate dry months (November and December). In the subregion 12.3 also, moisture availability period started from end of June and continued up to December with the normal LGP (200–250 days) and prominent moist period was observed during July–September and moderate dry period during November and December.

3.3. Mean monthly southwest monsoon rainfall at different probabilistic levels and its utility for crop planning

The probable date of onset of southwest monsoon in the region is 23rd–24th standard meteorological weeks in different districts and thus length of growing period (LGP) also starts from 23rd standard weeks. So sowing operation can be initiated from that week but prediction of southwest monsoon during rainy season is of paramount importance for assessing rainfall at highly assured level for raising crops successfully with high and stable yield because agriculture in AER 12.0 is southwest monsoon dependent. In this study monthly southwest monsoon (June–September) rainfall were predicted at 30%, 50% and

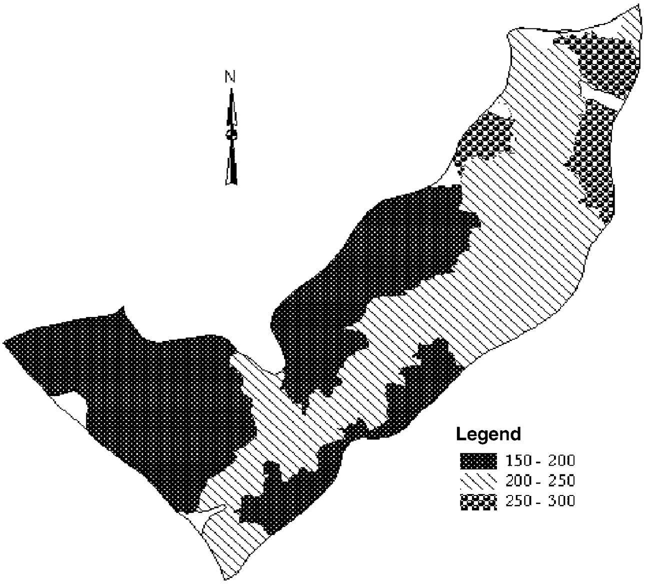

Fig. 6. Length of growing period (LGP, days) in AER 12.0.

80% probability levels using extreme value distribution type-1 probability model (Table 3). Study reveals that in the first monsoon month i.e., in June 98 to 156 mm rainfall occurred at 80% (most dependable limit) probability level in AER 12.1, 103 to 144 mm in AER 12.2, 93 to 132 mm in AER 12.3. Therefore the rainy season direct seeded crops namely groundnut (*Arachis hypogea* L.), pigeonpea (*Cajanas cajan* (L.) Millsp.), cowpea (*Vigna unguiculata* (L.) Walp), maize (*Zea mays* L.) and blackgram (*Phaseolus mungo* L.) can be sown and rice nurseries can be prepared in 23rd to 24th standard weeks with the commencement of monsoon in different parts of the AER 12.0. So the rainfall at dependable level during June can be utilized for upland direct seeded crop planning. In the month of July at 80% probability level, 216–222 mm in AER 12.1, 193–222 mm in AER 12.2 and 190–235 mm rainfall in AER 12.3 were predicted which can be utilized for rice transplanting starting from first fortnight of July in medium and low land rice ecosystems. The transplanting of rainy season rice in the first week of July will have additional advantage of assured rain during August and September.

To increase the rainwater use efficiency and productivity of light textured rainfed rice upland, rice can be substituted with other low water requiring crops through sole or intercropping. In case maize, groundnut, pigeonpea and direct seeded rice based intercrops could not be sown by the end of June or fail to establish in June due to dry spell or aberrant weather, then sowing of these crops should not be done afterwards because of delayed sowing of maize, groundnut or upland rice may cause crop failure or very low productivity. The crops like blackgram, cowpea, and sesamum can be sown successfully up to last week of July. Since the rainfall after October is uncertain and erratic, sowing of high value winter crops without supplementary irrigation is not possible in the region.

Table 3
Prediction of southwest monsoon rainfall (mm) at different probabilistic level

Districts	June			July			August			September		
	30%	50%	80%	30%	50%	80%	30%	50%	80%	30%	50%	80%
AESR 12.1												
Dhenkanal	226	178	118	330	280	216	513	332	102	229	197	156
Phulbani	213	165	104	348	293	224	406	329	231	240	196	141
Klahandi	255	199	128	400	339	262	398	334	253	246	195	130
Koraput	243	196	138	371	330	296	370	320	256	258	217	165
Mayurbhanj	270	220	156	319	277	223	384	326	252	314	251	172
Sambalpur	223	268	98	370	319	255	414	351	272	235	191	136
Sundergarh	238	188	125	378	321	249	382	329	262	232	189	134
Bolangir	224	170	101	365	314	249	390	321	232	213	166	106
AESR 12.2												
Cuttack	219	177	123	339	287	222	384	329	259	260	217	163
Balasore	272	216	144	294	250	193	355	303	236	288	235	168
Ganjam	197	156	103	253	212	161	279	231	171	245	201	144
Puri	217	171	117	334	278	212	372	320	250	250	212	153
AESR 12.3												
Keonjhar	243	195	134	314	280	236	373	323	260	273	230	175
Bankura	222	180	112	290	250	193	298	264	199	212	158	124
Purulia	211	172	94	286	244	190	295	248	195	210	134	128
Midnapore	232	200	132	296	268	219	312	270	208	231	180	142
Birbhum	198	169	99	270	240	192	290	245	190	208	151	120
Ranchi	120	163	112	282	245	201	296	230	198	214	150	128

3.4. Mapping cold periods for growing winter crops

The key ecological characteristics of cold requiring crops like wheat, *Brassica*, potato, chickpea, etc., are general adaptation of their photosynthetic and growth process to daily mean temperatures in the range of 15–19 °C and minimum temperature of 10–14 °C. In India both the start and end of the potential cold requiring crop season is limited by the onset and end of favorable weather mainly temperature, within the season itself warmer temperatures shorten the vegetative crop duration of these crops. This accounts for the decrease in the life duration and productivity of the cold requiring winter crops as one proceeds from North to South in the wheat, *Brassica* or potato belt of India. The AER 12.0, which comprises mainly Orissa, West Bengal, Jharkhand and Chhattisgarh state, farmers cultivate cold requiring crops irrespective of their suitability of growing or getting net return from these crops. Hence an attempt has been made to analyze thermal regime of the AER 12.0 to study feasibility of growing cold requiring crops commercially with good net economic return. In this study number of weeks of existence of favourable mean temperature of 15–19 °C and minimum temperature of 10–14 °C were identified and mapped into four zones (Fig. 7) using ARCVIEW GIS software. Study reveals that optimum mean favourable temperature of 15–19 °C and minimum temperature of 10–14 °C prevailed for 7–10 weeks in AESR 12.1, whereas in AESR of 12.2 (comprises of coastal belt of Orissa and Andhra Pradesh), these favourable temperature weeks prevailed only for 1–3 weeks, whereas in the AESR 12.3 (represents red and laterite zone of West

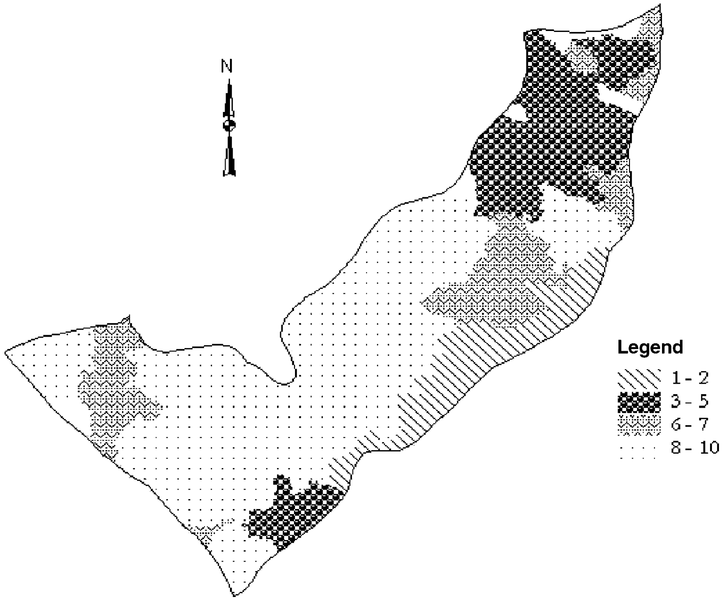

Fig. 7. Favourable temperature weeks for growing cold requiring crops.

Bengal and central and north-eastern plateau zone of Bihar), the favourable temperature persisted for 6–7 weeks. It was also found that in AESR 12.3 (Birbhum and Midnapore), favourable mean and minimum temperatures for growing cold requiring crops existed up to 04 standard meteorological weeks (last week of January), which coincided with flowering stage of wheat, *Brassica*, chickpea, etc., and tuber initiation stage of potato. But during pod formation stage of pulses and oilseeds, grain filling stage of wheat and tuber bulking stage of potato (05–08 standard meteorological weeks, first week of February onwards), minimum temperature increased abruptly which might restricts accumulation of photosynthates towards economic part of these cold requiring crops because of higher respiration. As a result these crops record low productivity in AESR 12.3.

Therefore, based on availability of favourable thermal regimes, the cold requiring crops may be grown in districts of AESR 12.1 particularly in Mayurbhanj, Sambalpur, Bolangir, Phulbani, Baster, etc., but before initiating commercial cultivation of these crops economic feasibility should be studied.

3.5. Reference evapotranspiration and spatial variability of crop water requirements (CWR) of rice

The evapotranspiration rate from a reference surface, not short or water is called the reference crop evapotranspiration (Allen et al., 1989), which was multiplied by the crop coefficient to obtain crop water requirements (CWR) at different growth stages. The ET_0 of different months in different districts was computed using FAO Penman–Monteith equation and are presented in Table 4.

Table 4
Computed crop reference evapotranspiration (mm)

	January	February	March	April	May	June	July	August	September	October	November	December
AESR 12.1												
Dhenkanal	112	137	195	240	279	207	136	146	120	133	108	105
Phulbani	78	87	136	168	174	147	105	108	99	105	78	68
Kalahandi	84	95	149	180	198	156	112	115	108	112	84	74
Koraput	77	87	136	156	170	132	93	99	93	103	78	71
Mayurbhanj	77	87	152	171	192	141	108	112	102	108	81	71
Sambalpur	90	109	158	198	236	108	112	118	111	118	90	81
Sundergarh	108	125	192	225	254	191	118	119	115	129	111	100
Bolangir	96	109	149	207	242	174	115	118	111	121	96	84
Chandrapur	107	124	189	219	280	213	139	127	119	125	99	87
AESR 12.2												
Cuttack	93	104	176	198	220	159	115	118	111	124	96	84
Balasore	96	109	180	201	217	156	118	121	111	118	96	87
Ganjam	124	123	170	162	177	150	121	130	123	136	126	118
Puri	124	129	167	159	174	150	127	136	132	146	126	121
Visakhapatnam	117	125	184	201	166	183	147	145	127	137	128	122
AESR 12.3												
Keonjhar	87	104	164	192	211	159	112	112	105	124	90	84
Bankura	75	82	136	135	178	142	110	121	105	87	83	67
Purulia	81	97	157	193	222	165	117	117	109	127	86	75
Midnapore	88	102	170	204	224	156	114	117	107	115	89	82
Ranchi	80	95	148	179	201	160	109	109	100	106	79	68
Dhanbad	90	107	163	210	224	165	115	117	110	117	91	83
Dumka	90	103	163	201	216	151	118	121	114	123	92	83

Climatic data source: Climatological table, IMD, New Delhi.

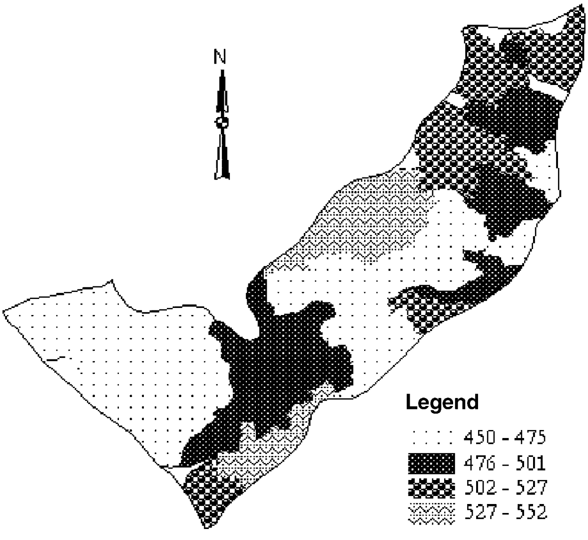

Fig. 8. Crop water requirements (mm) of autumn rice.

The AER 12.0 was dominated by rice and rice grew in the region in three different seasons namely autumn, winter and summer. In this study crop water requirements of rice during different growing seasons were computed using CROPWAT 4.0 model and attributes were linked with district polygon of AER 12.0.

The CWR of rice during different seasons in AER 12.0 are presented in Figs. 8–10 for autumn, winter and summer rice, respectively. Study revealed that CWR of autumn rice

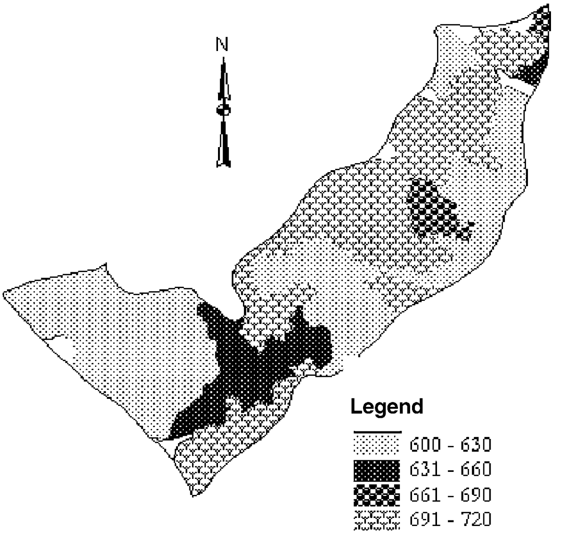

Fig. 9. Crop water requirements (mm) of winter rice.

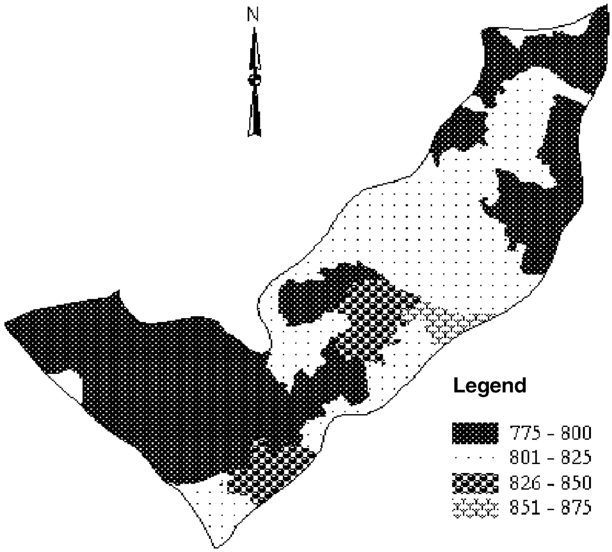

Fig. 10. Crop water requirements (mm) of summer rice.

ranged between 450 and 550 mm, whereas CWR of winter rice varied between 600 and 720 mm in different districts and AESRs. The CWR of summer rice was higher than rice of other seasons as per expectation, which varied between 775 and 875 mm. In regard to irrigation requirements, autumn rice and winter rice were having less irrigation requirement for all the AESRs because of occurrence of rainfall during rainy season (June–September), whereas during growing period of summer rice, rainfall was very less, as a result irrigation requirement was very high.

4. Conclusion

Study found that as per climatic water balance study, large to moderate water surplus (520–670 mm) was available in AESR 12.1. The rainfall surplus of 220–370 mm was computed in AESR 12.2 and 370–520 mm in AESR 12.3 mm. Since winter rainfall is meager and erratic this amount of rainfall may be harvested and utilized for providing supplemental irrigation to winter crops or during dry spell of rainy season crops. Study also reveals that at 80% probability level (highly assured) in first month of southwest monsoon (June) 98–156 mm rainfall occurs in AESR 12.1, 103–144 mm in AESR 12.2 and 93–132 mm in AESR 12.3. These amounts of rainfall are sufficient to prepare land and sowing of direct seeded crops like maize, groundnut, blackgram, greengram, pigeonpea, cowpea, etc.

Based on availability of favourable thermal regimes, the cold requiring crops may be grown in districts of AESR 12.1 particularly in Mayurbhanj, Sambalpur, Bolangir, Phulbani, Baster, etc., but before initiating commercial cultivation of these crops economic feasibility should be studied.

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References

Allen, R.G., Jensen, M.E., Wright, J.L., Burman, R.D., 1989. Operational estimates of reference evapotranspiration. Agron. J. 81, 650–652.

Allen, R.G., Pereira, L.S., Raes, L., Smith, M., 1998. Guidelines for computing crop water requirements. Irrigation and Drainage Paper No. 56, FAO, Rome, Italy.

Beinorth, F.H., Jones, J.W., Knapp, E.B., Papajorgi, P., Luijten, J., 1998. Evaluation of land resources using crop models and GIS. In: Tsuji, G.Y., Hoogenboom, G., Thornton, P.K. (Eds.), Understanding Options for Agricultural Production. Kluwer Academic Publishers, Dordrecht, pp. 293–311.

Doorenbos, J., Kassam, A.H., 1979. Yield response to water. FAO Irrigation and Drainage Paper No. 33, FAO, Rome, Italy, p. 193.

Doorenbos, J., Pruitt, W.O., 1977. Crop water requirements. Irrigation and Drainage Paper No. 24 (rev.), FAO, Rome, Italy, p. 144.

Environment System Research Institute (ESRI), 1998. Introduction to Arc View GIS. ESRI, Redlands, CA.

Hansen, J.W., Jones, J.W., 2000. Scaling-up crop models for climatic variability applications. Agric. Syst. 65, 43–72.

Hartkamp, A.D., White, J.W., Hoogenboom, G., 1999. Interfacing geographic information systems with agronomic modelling: a review. Agron. J. 91, 761–772.

Heinemann, A.B., Hoogenboom, G., 2000. Optimization of the capacity of center pivot irrigation systems based on drybean model CROPGRO. Annual report of the Bean Improvement. The XXXXIII Report of the Bean Improvement Cooperative, vol. 43, Michigan State University, East Lansing, MI, pp. 132–133.

Lal, H., Hoogenboom, G., Calixte, J.P., Jones, J.W., Beinorth, F.H., 1993. Using crop simulation models and GIS for regional productivity analysis. Trans. ASAE 36 (1), 175–184.

Smith, M., 2000. The application of climate data for planning and management of sustainable rainfed and irrigated crop production. Agric. Forest Meteorol. 103, 99–108.

Thornthwaite, C.W., Mather, J.R., 1957. Instructions and Tables for Computing Potential Evapotranspiration and Water Balance, 10. Laboratory of Climatology, Drexel Institute of Technology, pp. 185–311.

Tripathy, R.P., 2004. Evapotranspiration and crop coefficients for rice, wheat and pulses under shallow water table conditions of Tarai region of Uttaranchal. J. Agrometeorol. 6 (1), 17–29.

Velayutham, M., Mandal, D.K., Mandal, C., Sehgal, J. (Eds.), 1999. Agro-ecological Subregions of India for Planning and Development. Publication No. 35, NBSS & LUP, Nagpur, Maharastra.