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Comparison of different models for estimation of net primary productivity in India

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ABSTRACT

Net primary productivity (NPP) and biomass production potential were estimated for 167 stations of India by different models using weather parameters downloaded from CLIMWAT database of FAO. Moisture adequacy index (MAI) as suggested by Hargreaves was calculated. Chikugo model (NPP_{ch}), Miami models (NPP_{mp}) and (NPPmt); Thornthwaite (NPP_{th}) and Waginengen, (BIO_{wag}) models were selected for estimating NPP. Correlation and best fit regression equations between MAI and NPP values showed positive relation with Chikugo (NPP_{ch}) and Miami based on precipitation (NPP_{mp}) models but negative relation with others. Negative relations of MAI and NPP are not natural therefore the suitability of those models was rejected. The correlation coefficient with MAI to NPP_{ch} & NPP_{mp} was 0.76 and 0.71 respectively. Chikugo model (NPP_{ch}) was found to be more sensible than Miami model because it estimated NPP in a broader range. The best fit equation developed using NPP_{ch} and MAI values showed a logarithmic relation (NPP_{cheq} = 32.6 ln (MAI) + 33.13, R^2 = 0.788) confirming that the net primary productivity by Chikugo model can also be estimated for the country using this as an alternative equation.

Keywords : Net primary productivity, biomass potential, moisture adequacy index (MAI), Chikugo model, Precipitation.

Net primary productivity (NPP) a key component of biogeochemical cycle is defined as the amount of dry matter produced by plants per unit time and space. NPP reflects the capacity of plants to capture solar radiation for carbon fixation into the ecosystems in the form of organic matter. NPP estimation enables us to identify the gap in the ecosystem potential to the actual NPP, which would give way to carbon sequestration into the ecosystems in the face of climate change. Various models to estimate NPP for diverse climatic conditions such as, Chikugo model (Uchijima and Seino, 1985) for Japanese condition, Miami models (Leith, 1972) for US condition, Thornthwaite model (Leith, 1972) for European condition have been developed to estimate forest yield. The Wageningen model (Doorenbos and Kassam, 1979) has been developed to estimate gross dry matter (GDM) production to estimate crop yield. NPP estimates from different models varied considerably in view of the difference in their input parameters. A suitable procedure to estimate the terrestrial NPP for the territory of the country is not available.

Hargreaves (1971) defined the moisture adequacy index (MAI) as the ratio of rainfall to the estimated potential evapotranspiration for the concerned period. He classified the condition as very deficient (<0.33 MAI), moderately deficient (0.34-0.67 MAI), somewhat deficient (0.68-1.0 MAI), adequate moisture (1.00-1.33 MAI) and excessive moisture (>1.34 MAI). Vegetative growth and forest cover in the moist areas is very high as compared to deficit areas. In view of these facts, the objective of this study is to select out a suitable NPP model for Indian condition using MAI as a scale.

MATERIALS AND METHODS

CLIMWAT 2.0 is a joint publication of the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO which offers normal weather data for about 5000 stations across the world. Weather data from the CLIMWAT database was taken to estimate net primary productivity (NPP) and gross dry matter (GDM) production for 167 stations of India. Moisture adequacy index (MAI) as per the procedure suggested by Hargreaves (1971) was calculated for all the stations of the country. Best fit equation and correlation coefficient between MAI and NPP were developed.

Chikugo model

Chikugo model proposed by Uchijima and Seino (1985) is based on the precipitation (mm day^{-1}) and net radiation. It estimates NPP (t ha^{-1} yr^{-1}) from Budyko's radiative dryness index (Budyko, 1956) and net radiation (Rn). RDI is a measure of the water use efficiency of the crop:

$$NPPch = 0.29 * [\exp(-0.216 * (RDI)^2)] * Rn$$

Where,

NPP_{ch}= Net primary productivity (t ha^{-1} yr^{-1})

P = Precipitation (mm day^{-1}).

RDI = Budyko's radiative dryness index calculated as Rn/P.

Rn = Net radiation (mm day^{-1}).

Miami models

Leith (1972) proposed Miami models for the assessment of NPP (g $m^{-2}yr^{-1}$) using mean annual temperatures (^{0}C) and mean annual precipitation (mm) in separate equations. The NPP value calculated using both the Miami models and found to be lowest is considered as the NPP of that area and expressed as:

NPP = Minimum (NPP_{mt} or NPP_{mp}) whichever value is minimum

Whether temperature or precipitation is limiting the lowest value of NPPmt and NPPmp is eventually retained.

NPP as a function of temperature (g $m^{-2}yr^{-1}$)

$$NPP_{mt} = \frac{3000}{1+e^{1.315-0.119T}}$$

NPP as a function of precipitation (g $m^{-2}yr^{-1}$)

$$NPP_{mp} = 3000 * (1 - (e^{(-0.000664)*P}))$$

Thornthwaite and Mather

This model also proposed by Leith (1972), calculates NPP (g $m^{-2}yr^{-1}$) in terms of the mean annual potential evapotranspiration (mm/yr^{-1}). This method is considered to be near accurate as it involves the evapotranspiration process which is closely related with photosynthesis and combined temperature and precipitation.

$$NPP_{th} = 3000(1 - e^{-0.0009695*ET})$$

Wageningen method

Doorenbos and Kassam (1979) proposed Wageningen method to estimate gross dry matter production potential as mentioned below:

$$Y_o = F*y_o + (1 - F) * y_c$$

Where,

Y_o = GDM production of a standard crop (kg ha^{-1} day^{-1}).

F = Fraction of the daytime the sky is clouded and calculated as ((Rse – 0.5*Rs) / 0.8Rse).

Rse = Maximum active incoming shortwave radiation on clear days (mm day^{-1} or cal cm^{-2} day^{-1}) (Table 1)

Rs= Active measured/calculated incoming short wave radiation (calcm^{-2} day^{-1}).

Rs= (0.25+ (0.5 *n/N) Ra

n= Actual sunshine (Hrs).

N= Maximum possible sunshine (Hrs) (Table 1)

Ra= Extra terrestrial radiation (cal cm^{-2} day^{-1}) (Table 1)

y_0 = gross dry matter production rate of a standard crop for a given location on a completely overcast day (kg $ha^{-1}day^{-1}$) (Table 1)

y_c = gross dry matter production rate of a standard crop for a given location on a clear (cloudless) day Conversion 1.0 mm = 59 cal cm^{-2} (Table 1)

Contour map of MAI and NPP values calculated by different models were plotted on the map of India using Arc GIS. Regression equation were developed using MAI and NPP values of 167 stations in India using Microsoft Excel.

RESULTS AND DISCUSSIONS

The latitude & longitude, moisture adequacy index (MAI), NPP by Chikugo, Miami's, Thornthwaite as well as the Wageningen methods are presented in forthcoming paragraphs.

Moisture adequacy index (MAI)

Moisture adequacy index (MAI) is the expression of atmospheric water balance using the value of precipitation and reference evapotranspiration or evaporation. The MAI value varied between 0.12 in Leh (extremely dry) and 12.26 in Cherapunji (extremely wet) in India. This is a well established fact that wet zones have

Table 1: Maximum active incoming shortwave radiation (Rse in cal $cm^{-2}day^{-1}$) and gross dry matter production on overcast day (yo) and clear Days (yc) (in kg ha^{-1} day^{-1}) for a standard crop, extra terrestrial radiation (Ra) (mm day^{-1}) and mean daily duration of maximum possible sunshine hours (N).

Lat. (^{0})N	Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	Rse	343	360	369	364	349	337	343	357	368	365	349	337
	yc	413	424	429	426	417	410	413	422	429	427	418	410
	yo	219	226	230	228	221	216	218	225	230	228	222	216
	N	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Ra	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8
10	Rse	299	332	359	375	377	374	375	377	369	345	311	291
	yc	376	401	422	437	440	440	440	439	431	411	385	370
	yo	197	212	225	234	236	235	236	235	230	218	203	193
	N	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
	Ra	13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9
20	Rse	249	293	337	375	394	400	399	386	357	313	264	238
	yc	334	371	407	439	460	468	465	451	425	387	348	325
	yo	170	193	215	235	246	250	249	242	226	203	178	164
	N	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
	Ra	11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7
30	Rse	191	245	303	363	400	417	411	384	333	270	210	179
	yc	281	333	385	437	471	489	483	456	412	356	299	269
	yo	137	168	200	232	251	261	258	243	216	182	148	130
	N	10.4	11.1	12.0	12.9	13.6	14.0	13.9	13.2	12.4	11.5	10.6	10.2
	Ra	8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3
40	Rse	131	190	260	339	396	422	413	369	298	220	151	118
	yc	219	283	353	427	480	506	497	455	390	314	241	204
	yo	99	137	178	223	253	268	263	239	200	155	112	91
	N	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
	Ra	6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7

Courtesy (Ref): Doorenbos J. And Kassam A.H. (1979)

better vegetative growth potential as compared to dry zones. As per the Hargreaves (1971) classification, agroclimate of India varies from extremely dry to extremely moist, therefore MAI can have a positive and logical relation with NPP.

Net primary productivity (NPP)

The average NPP calculated by different methods for 167 stations of India was recorded as 23.6 (ranging from 0.5-104.2) t $ha^{-1}yr^{-1}$ by Chikugo (NPP_{ch}) model (Fig.1), 16.2 (ranging from 2.2-30.0) t $ha^{-1}yr^{-1}$ by Miami precipitation based (NPP_{mp}) model (Fig.2), 25.1 (ranging from 10.2-26.9) t $ha^{-1}yr^{-1}$ by Miami temperature based ($NPP_{mt)}$ model, 44.2 (ranging from 20.3-64.9) t $ha^{-1}yr^{-1}$ by Thornthwaite & Mather (NPP_{th}) model whereas 119.7 (ranging from 101-131) t $ha^{-1}yr^{-1}$ by Wageningen ($BIOM_{wag}$) method. Out of the five models, the first four models estimated the output of NPP almost closure to each other

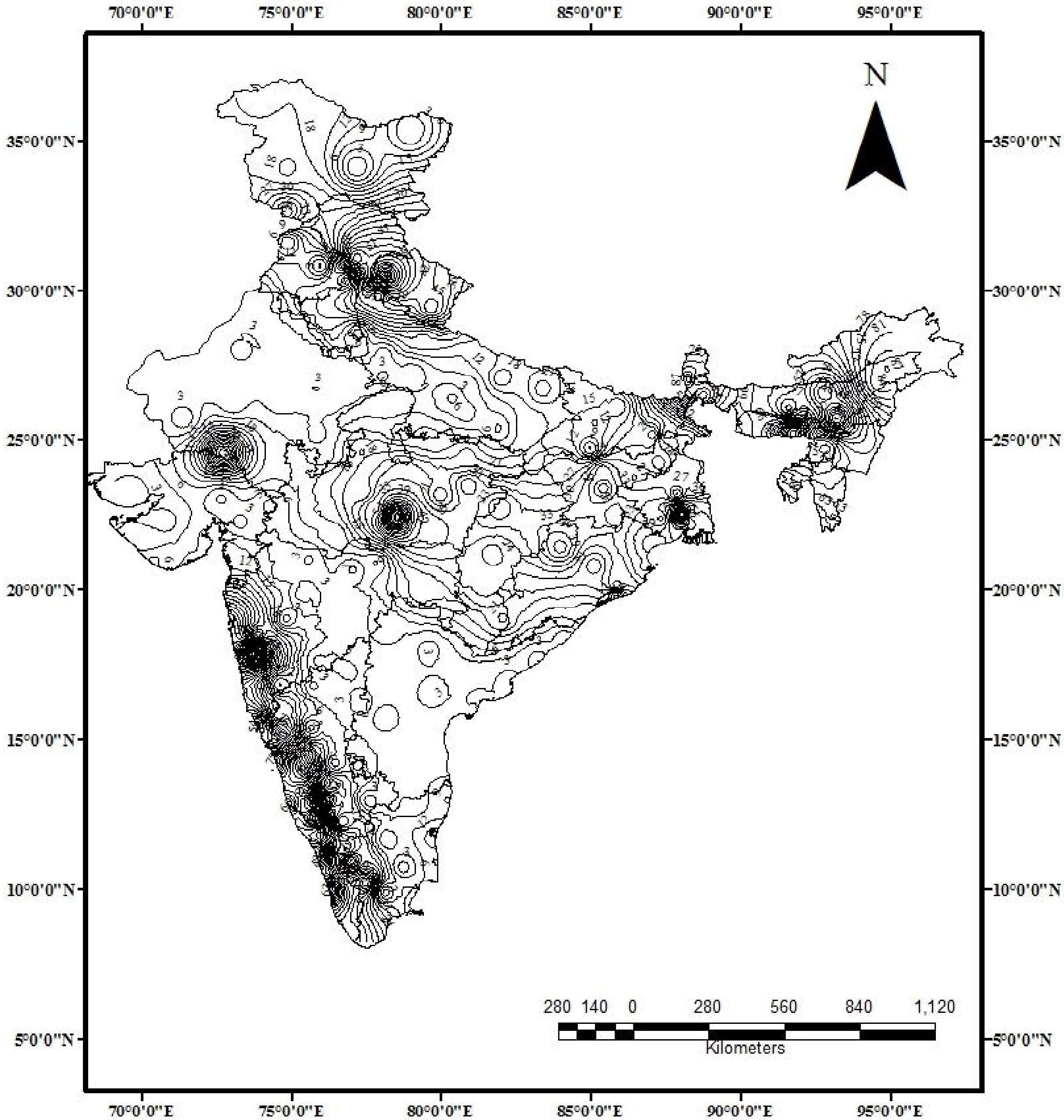

Fig. 1: Contour map of NPP estimated by Chikugo model for India.

(16.2-44.2 t ha^{-1}yr^{-1}) but the last method recorded extremely high values (119.7 t ha^{-1}yr^{-1}). This could be attributed to the fact that the first four models were developed to estimate the forest yields whereas the fifth method was developed to estimate the crop yield. Variation in the estimate of NPP by different models could be attributed to the difference in the background in which they were developed. For instance the Chikugo model (NPP_{ch}) was developed for the conditions of Japan, Miami (NPP_{mt} & NPP_{mp}) models were developed for the conditions of USA and Thornthwaite (NPP_{th}) model was developed for the conditions of Europe. Unfortunately there is no specific model developed for the conditions of India. It would therefore be wise to select one of them that could give satisfactory estimate applicable to Indian condition.

MAI and NPP relation

Correlation studies between MAI and the estimates of the NPP models presented in Table 2 showed that out of five methods, the two models (NPP_{ch} and NPP_{mp}) recorded positive correlation with MAI whereas the rest of the models recoded negative correlation. Positive correlation

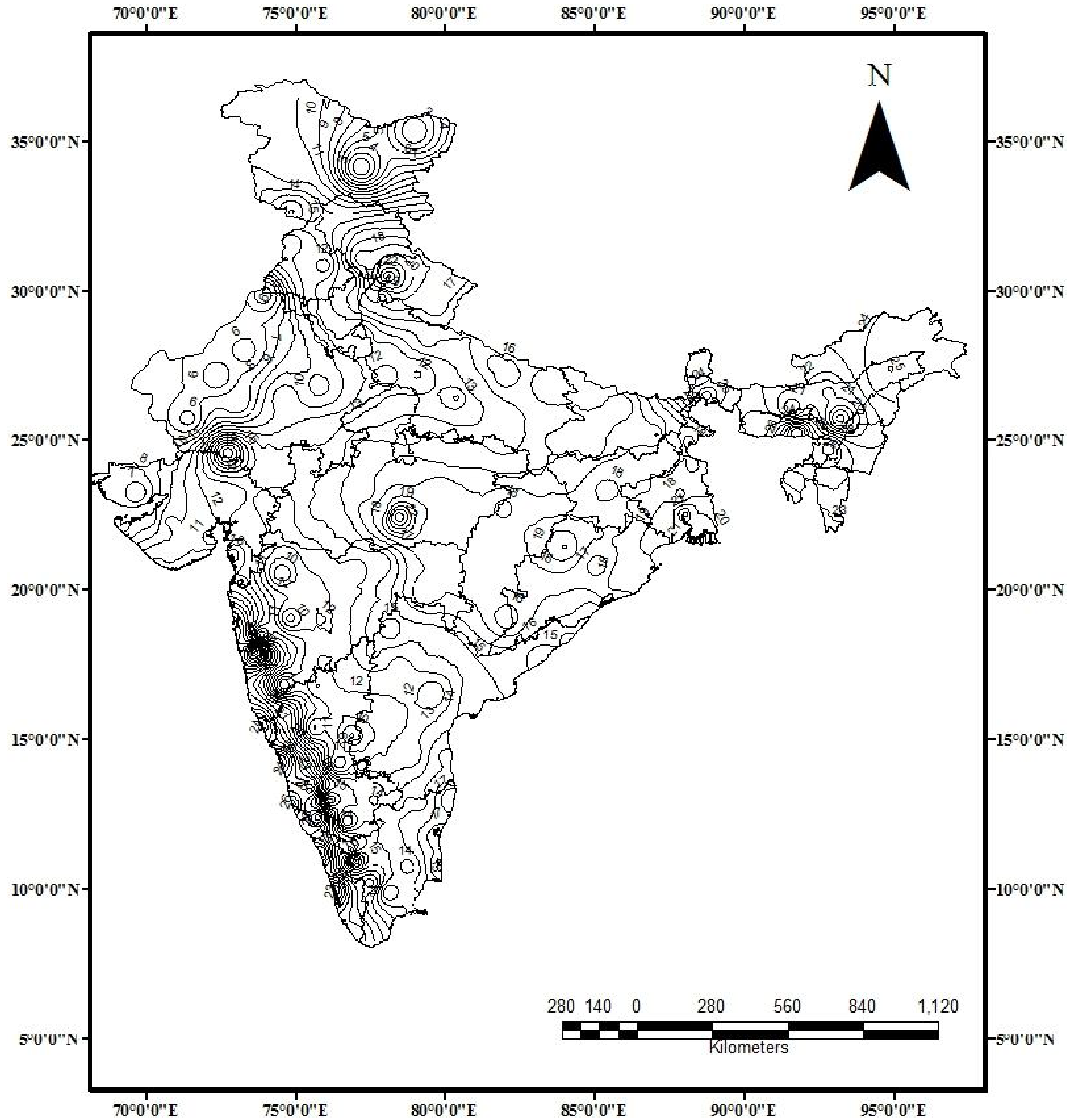

Fig. 2: Contour map of NPP estimated by Miami model (precipitation based) for India.

between MAI and NPP estimate is logical as the vegetation growth increases with the increase in the moisture condition but the negative correlation is not logical. The Chikugo model and NPP_{mp} although recorded a positive relation with MAI but there was huge difference in estimate. NPP_{mp} method estimated 2.2 t $ha^{-1}yr^{-1}$ corresponding to 0.12 MAI and 29.97 t $ha^{-1}yr^{-1}$ at 12.26 MAI whereas the NPP_{ch} estimated 0.5 t $ha^{-1}yr^{-1}$ at 0.12 MAI and 104.2 t $ha^{-1}yr^{-1}$ at 12.26 MAI. Estimate of NPP_{ch} appears to be reasonable because the range of estimate is large and correlation is highest. In view of this, the net primary productivity estimation by Chikugo model (NPP_{ch}) could be recommended for the country.

Regression equations developed using MAI and NPP values estimated by the first two methods are presented in Fig.4. The wider range of NPP estimate obtained against the wide range MAI in the Chikugo model is the primary cause of its acceptability therefore recommended to adopt for the conditions of India. The regression equation ($NPP_{cheq} = 32.6 \ln (MAI) + 33.13$, $R^2 = 0.788$) developed with MAI and net primary productivity by Chikugo model (NPP_{ch}) has a logarithmic relationship. The estimate of net primary productivity equivalent to Chikugo model (NPP_{cheq}) using MAI is a simplified and alternative approach to calculate

Table 2: Correlation coefficient between MAI and NPP estimated by different models.

S.No	Model	NPP range(t $ha^{-1}yr^{-1}$)	Corr. Coeff.	Remark
1	Chikugo Model (NPP ch)	0.5-104.2	0.76	Broader Range
2	Miami model with prec. (NPP mp)	2.2 - 30.0	0.71	Narrow Range
3	Miami model with Temp.	10.2-26.9	-0.33	Narrow Range
4	Thornthwaite & Mather Model	20.3-64.9	-0.54	Narrow Range
5	Wagensingen Method	101-131	-0.35	Narrow Range

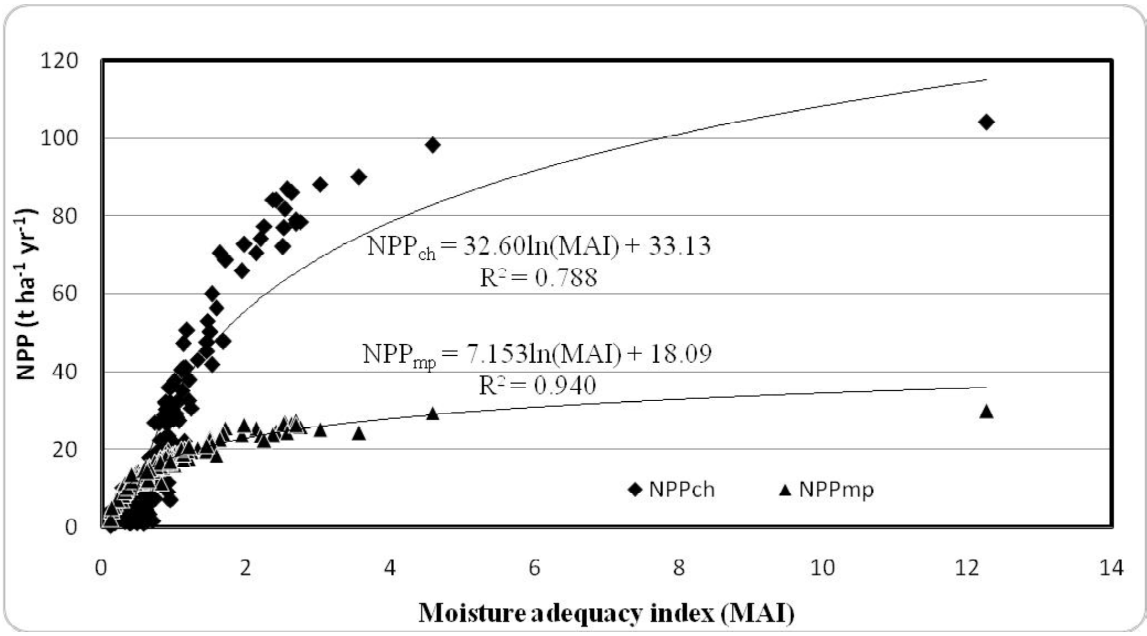

Fig. 3: Relationship between MAI and NPP estimated using different models for India.

NPP equivalent to Chikugo model therefore recommended for different agro climatic conditions of India.

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PAPER 1