Forest Science and Technology

ISSN: 2158-0103 (Print) 2158-0715 (Online) Journal homepage: http://www.tandfonline.com/loi/tfst20

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Forest Science and Technology
Vol. 11, No. 3, September 2015, 126–132

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Forest and agro-ecosystem productivity in Bangladesh: a climate vegetation productivity approach

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(*Received 26 July 2014; Accepted 17 August 2014*)

The aim of the study was to assess spatial and temporal variation in productivity with respect to climate factors in Bangladesh in different forest ecosystems and agro-ecological zones. A climate vegetation, and productivity index (CVPI) for different vegetation types of Bangladesh were measured for years ranging between 1990 and 2010. Data were gathered from 11 meteorological stations sporadically distributed throughout the country. The range of CVPI at different vegetation zones of the country shows values between 1223 and 2800 (this index has no unit). Spatial distribution of values indicates that CVPI is lower in northwestern and southwestern agro-ecological zones of the country, whereas it is higher in eastern zones. This may be due to less rainfall and higher atmospheric temperature in the western part than the eastern part. CVPI in the central part of Bangladesh also decreases while the temporal scenario also varies significantly. There was a peak in the index during the year 1998 when the country faced extreme precipitation followed by devastating floods. Both spatial and temporal variation depicts that vegetation productivity would increase or decrease with respect to climatic parameters such as mean monthly temperature, precipitation, and solar radiation received at the site. For major types of forested woodland, tropical evergreen and semi-evergreen types cover the range of 2150–2800, moist Sal forest covers 1223–1896, dry Sal forest covers 1277–1280, Sundarbans covers 1307, and coastal plantations cover 1946–2531 CVPI. This value greatly depends on the spatial coordinates of the meteorological stations. From Paterson's regression, forest timber productivity was calculated which was found to be higher for evergreen, semi-evergreen, and coastal plantation (about 10–11 m^3 ha^{-1} yr^{-1}), where deciduous Sal and Sundarbans has lower productivity (about 8–9 m^3 ha^{-1} yr^{-1}) than hill forests. Thus, climatic factors, as well as altitudinal and latitudinal differences, may pose divergence in forest productivity. Hence, climate is the key factor in forest productivity and distribution.

Keywords: Bangladesh; CVPI; AEZs; forests ecosystems; productivity

Introduction

It is evident that there is a close relationship between climate and the vegetation it supports (Champion et al. 1965). Since biogeographers and ecologists seek a relationship between vegetation productivity and climatic factors within regions, scientists such as Paterson (1956) and Weck (1957) introduced their climate-vegetation-productivity (CVP models. The productivity of the climax vegetation on a site depends on the maximum sustained utilization of the environmental resources. When physiographic and soil factors are optimum, the productivity of a site is chiefly determined by the climatic factors (e.g., solar radiation reaching the ground, amount of water available for life processes and the period during which temperature is favourable to growth; Champion et al. 1965). So far, the best-known climatic index for predicting forest productivity is Paterson's CVP index (CVPI; Vanclay 1992). Based on the close correlation found between this index and the known forest productivity of certain sites, Paterson has subsequently computed the potential production of forest areas throughout the world (Jackson 1965).

Paterson (1956) defined the CVPI as one of the significant methods for assessing the productivity of any vegetated land which correlates the relationship between climate and biosphere productivity. Traditionally, this index has been used for large areas, even on a global scale (Paterson 1956; Weck 1957). Nevertheless, with the aid of new technologies and the existence of more and better datasets, this index has been applied on regional scales to Scandinavia by Paterson in 1962 and to Pakistan and Bangladesh (former East Pakistan) by Champion et al. in 1965, and on a national scale to a number of countries such as Sweden (Paterson 1959), France (Pardé 1959), Australia (Howden and Gorman 1999), eastern Canada (Lemieux 1961), India (Kant 2005), and Spain (Benavides et al. 2009; Palomares and Serrano 2000). All found CVPI as a useful tool for quantifying forest productivity, except for Jackson (1965) who identified some limitations with the index. The present study was conducted to assess the potential productivity of forest vegetation with respect to climate factors using Paterson's CVPI once again in Bangladesh.

Bangladesh has a humid, warm, tropical climate, which is influenced primarily by monsoon and partly by pre-monsoon and post-monsoon circulations (Agarwala et al. 2003). The mean monthly rainfall is about 192 mm, and mean monthly temperature is about 25–30°C;

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ISSN 2158-0103 print/ISSN 2158-0715 online

http://dx.doi.org/10.1080/21580103.2014.957358
http://www.tandfonline.com

Table 1. Study site information (1990–2010).

Forest ecosystems (FAO 2007; Das 1982)	Meteorological station	Geo-position: Latitude	Longitude	Mean monthly temperature (°C)	Mean monthly precipitation (cm)
Evergreen–semi-evergreen	Chittagong	22°16′ N	91°49′ E	26.31	258
	Cox's Bazar	21°26′ N	91°56′ E	27.89	262
	Sylhet	24°95′ N	91°85′ E	25.29	195
Wet deciduous (moist Sal)	Dhaka	24°10′ N	91°00′ E	25.67	160
	Tangail	24°15′ N	89°55′ E	25.52	145
	Mymensingh	24°43′ N	90°26′ E	25.07	176
Dry deciduous (dry Sal)	Rajshahi	24°22′ N	88°42′ E	25.96	124
	Dinajpur	25°80′ N	88°90′ E	26.45	119
Sundarbans mangrove	Khulna	22°47′ N	89°32′ E	26.41	153
Mangrove plantations	Patuakhali	22°20′ N	90°20′ E	26.21	225
	Maizdicourt	22°52′ N	91°06′ E	25.43	213

however, there exists a wide spatial and temporal distribution (MPO 1991). Bangladesh has subtropical evergreen and deciduous forest tree species that has potential growing capacity to be included in economic forestry activities like massive plantation (Das 1982) or in carbon forestry projects (Rahman and Akter 2013). Total forestlands are about 2.53 million ha of which 0.67 million ha have been classified as evergreen and semi-evergreen forest, 0.12 million ha as tropical moist deciduous forest, and 0.67 million ha as mangrove forest (Hossain 2005; FAO 2007). Forest productivity of the country in terms of wood biomass is satisfactory as the country falls under tropical and subtropical zone (FRA 2010). Moreover, agro-ecological regions of the country may represent agricultural vegetation of which productivity needs to be assessed. There are 30 agro-ecological zones (AEZs) in the country (FAO 1988). Therefore, a need may exist to evaluate potential forest productivity along with other vegetation with respect to its driving factors such as climate factors (e.g., temperature, precipitation, sunshine hour, growing season etc.). Thus, the present study aims to evaluate vegetative productivity of Bangladesh spatially and temporally using meteorological data to apply Paterson's CPVI.

Materials and methods

Materials

ArcGIS Version 10 software was used to prepare and visualize the maps. For analyzing climatic parameters, long-term weather data of minimum and mean minimum temperature, maximum and mean maximum temperature, mean humidity, sunshine hours, and rainfall from 1990 to 2010 for 11 sporadically distributed weather stations were collected from the Bangladesh Meteorological Department.

Study site

The study site represents 11 meteorological stations of the country. These stations are distributed at sporadic locations of the country covering major forest types and agro-ecological zones of Bangladesh. Relevant geopositional, climatic, and ecological information are plotted in Table 1.

CVPI calculation

Paterson (1956) showed that when physiographic and soil factors are optimum, the productivity of the site is chiefly determined by climatic factors (e.g., solar radiation reaching the ground, amount of water available for life processes and the period during which temperature is favourable to growth). Paterson's CPVI is given by the following formula:

$$\text{CVP index, ICVP} = (\text{Tv}\times\text{P}\times\text{G}\times\text{E})/(\text{Ta}\times 12\times 100) \quad (1)$$

where, T_v is the mean maximum temperature during the year in degrees centigrade, Ta is the range between the mean maximum and the mean minimum in °C, P is the mean annual precipitation in mm, and G is the growing period in months. It represents the number of months during which the mean monthly temperature exceeds 30 °C in warm climates. De Martonne's index of aridity (see equation 2; De Martonne 1926) was used to determine G and expressed as mm °C^{-1}. Only the humid months with an index above 20 are included in the growing season.

$$I_{Ar}\,DM = 12p/(t+10) \quad (2)$$

where p denotes the mean monthly precipitation in mm and t the mean monthly temperature in °C, and E is the radiation received at the pole expressed as a percentage of the radiation received at the latitude in question.

Productivity calculation

If considering productivity in terms of volumetric calculations, using Paterson's dynamic regression, the following regression equation was used to assess forest productivity in terms of volume production which was enumerated

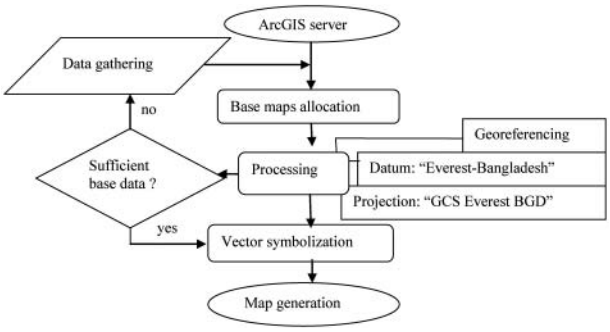

Figure 1. Flow chart of methodology in GIS environment.

by m^3 ha^{-1} yr^{-1} (Paterson 1956):

$$Y = 5.20 \log X - 7.25 \tag{3}$$

This formula estimates forest productivity in ideal sites under ideal conditions of management (Champion and Seth 1968; Lal 1992). Here X is the value of calculated CVP and Y is potential forest productivity. Paterson used this to calculate global forest productivity at different sites and found a significant result, which was later adopted by Champion et al. (1965) for East Pakistan (present Bangladesh).

GIS application for mapping

The method of geographic information system (GIS) is a specialized skill. It requires simultaneous knowledge on word processing, spreadsheet analysis, database file management, and also file imaging (methodology adapted from Al-Amin and Rahman 2011). Figure 1 indicates how the method was conducted in the ArcGIS server to visualize and symbolize the data in the map.

Results

Spatial distribution of CVPI for different AEZs of Bangladesh

Average values of CVPI through different stations were plotted on agro-ecological regions of Bangladesh to assess the potential vegetation productivity (Figure 2). The CVPI value is slightly lower in the northwestern and southwestern parts of the country, but is comparatively higher in the eastern part. This may due to less rainfall and higher atmospheric temperature in the western part than the wastern part (Shahid 2010). This is because the CVPI value depends on the climatic data (mean maximum temperature and precipitation) of any locality. The CVPI value in the central part also decreases with respect to the eastern part of the country. Thus, the productivity of the forest biomes will depend on the climatic parameters.

Year wise CVPI calculated at different meteorological stations

The CVPI value at different meteorological stations of the country (Chittagong, Cox's Bazar, Maizdicourt [Noakhali], Tangail, Patuakhali, Rajshahi, Khulna, Mymensing, Sylhet, Dinajpur, and Dhaka) were plotted and recorded temporally from 1990 to 2010. Results showed that, for climatic variation at different years (Table 1) pose variation in CVP values at different stations temporally. Figure 3 depicts that, for the year 1998, CVPI values were higher in the Noakhali, Chittagong, and Cox's Bazar regions. Subsequent rises during the years 1990, 1993, and 2000 was found in most of the coastal regions such as Noakhali and Cox's Bazar.

CVPI value for major forest woodlands of Bangladesh

Table 2 indicates CVPI values calculated for the different forest types of Bangladesh. Here, highest value covers within tropical evergreen and semi-evergreen forest, which is situated in the eastern part of the country. However, lower values in moist dry Sal forest and mangrove forest as these forests are situated in the central part and western part, respectively.

Forest productivity in terms of volume production was found to be higher in evergreen and semi-evergreen ecosystems and in coastal mangrove plantation; however, deciduous Sal forest and Sundarbans mangrove forest was found to be low in producing timber volume. This may be due to ecological and climate consequences as the measurements were strictly adjacent to climatic parameters.

Discussion

The CVPI has not been assessed or used in Bangladesh for many years. However, this is the key process to determine the climatic productivity potential of any region. Spatially, this tool helps to indicate an area's potential with respect to its vegetation growth according to its climatic parameters.

The methodological approach

The CVPI is probably only useful for economic geography and general forest statistics where estimates of potential production are required for large inaccessible and non-inventoried areas (Lemieux 1961). In that context, large inaccessible areas where inventory is expensive, such as hill and mangrove forests (FRA 2010), could assessed by this method. The CVPI estimation is simple to apply in its basic form, using monthly averages and applicable only to sites with optimal soil depth, adequate fertility and adequate soil aeration, averaged over species (Howden and Gorman 1999). In spite of its limitations, it can be very useful for comparing zones located within the same region, regardless of the presence or absence of trees, the age of the stand, or the species (Vanclay 1992). It could serve to provide a valuable indication of the maximum likely steady-state increment of stemwood dry matter of 'mature' stands, and hence long-term carbon sequestration rate, as well as more complex models (Howden and Gorman 1999).

Despite its limitations, Paterson's CVPI may be used in all vegetation types irrespective of time. Jackson

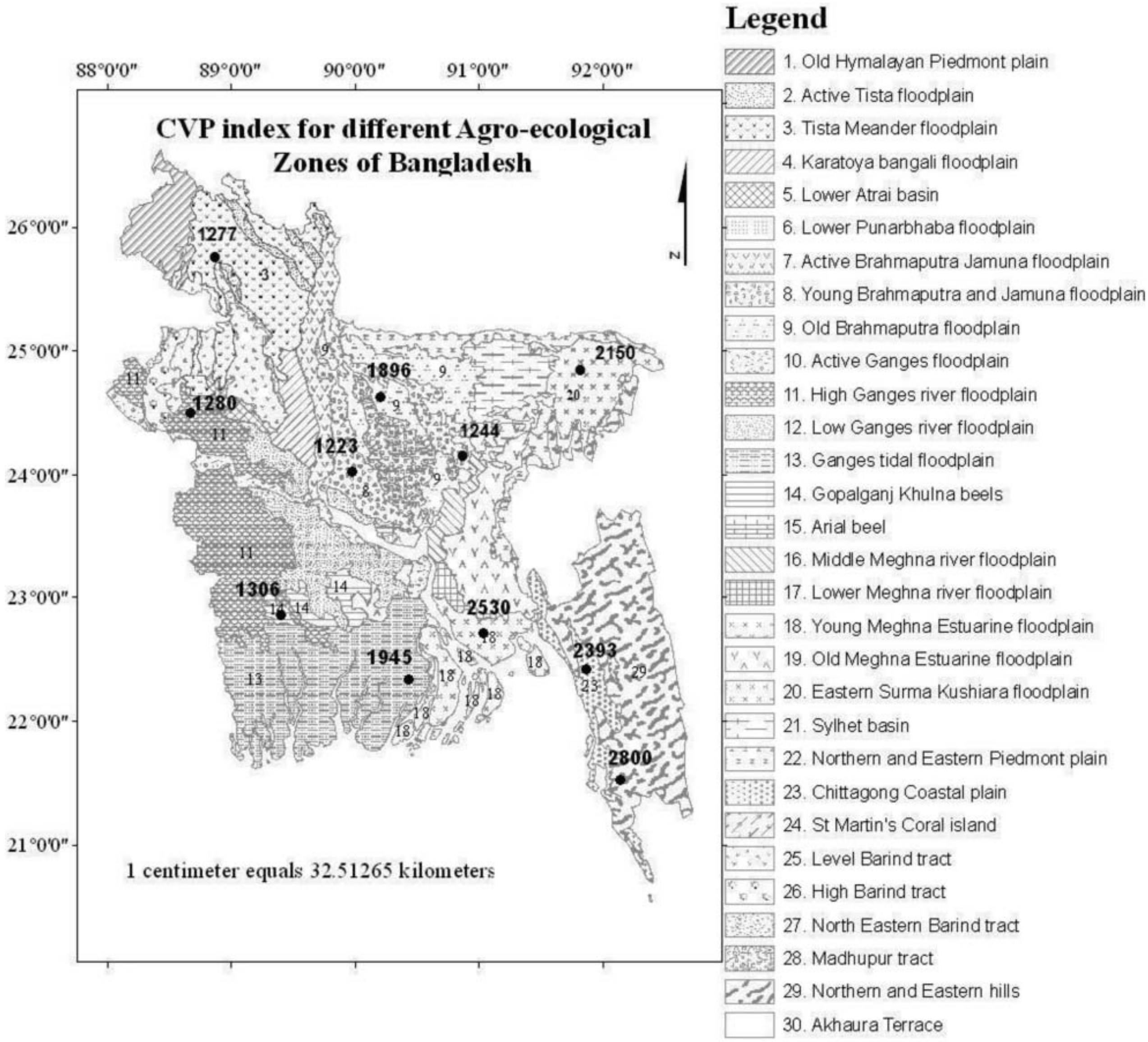

Figure 2. Map showing CVPI values at selected agro-ecological zones in Bangladesh.

(1965) directed two major criticisms at the CVPI. First, it measures timber volume instead of dry matter (biomass) while comparing site classes because it is designed to predict the maximum growth potential in terms of volume production (Hägglund 1981; Johnston et al. 1967), and, second, it does not consider soil factors. Some other limitations are using pre-selected climatic parameters which exclude insulation, exposure, aspect, and humidity.

Calculation of CVPI is site independant (Sajjaduzzaman et al. 2005); that means it is irrespective of any particular stand or any edaphic factors (Vanclay 1994).

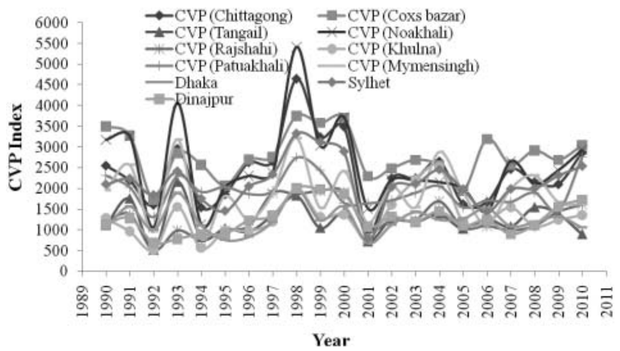

Figure 3. Year wise CVPI values at different meteorological stations.

Climate-productivity relation

Climate explains the regional variation in tree growth, but the climate effect is diluted at the stand level (Vanclay 1994). These climatic variables including radiation, precipitation, and temperature influence species composition and productivity (Stage and Salas 2007). Dry regions contain lower productivity than wet tropical regions with favorable climates. To assess the crop production potential, length of the growing period zones (a concept introduced by the UN Food and Agriculture Organization) is very useful as it describes an area within which rainfall and temperature conditions are suitable for crop growth

Table 2. CVPI and forest volume productivity at different ecosystem sites.

Forest ecosystems	Calculated CVPI	Productivity ($m^3\ ha^{-1}\ yr^{-1}$)	CVP by Champion et al. 1965
Evergreen–semi-evergreen	2150–2800	10.36	2000–3000
Wet deciduous (moist Sal)	1223–1896	9.15	1000–2000
Dry deciduous (dry Sal)	1277–1280	8.91	500–1000
Natural mangrove (Sundarbans)	1307	8.95	
Mangrove plantations	1946–2531	10.15	

for a given number of days in the year. Parameters such as temperature regime, total rainfall, and evapotranspiration, and the incidence of climatic hazards are more relevant when calculated for the growing period when they may influence crop growth, rather than averaged over the whole year (FAO 1996).

From equation 1 it is evident that there are some factors such as a wide range of temperature in any month, lower precipitation, lower solar radiation received, and more drier months which may induce a lower CVPI value and vice versa.

Weck (1957) set a lower threshold of two months for the growing season as a necessity for forest and woodland ecosystems. An advantage of the De Martonne's index (I_{Ar} DM) has been its use in Paterson's CVP model (Paterson 1956; Pardé 1958) for forest stands. It was calibrated against tree productivity on favorable sites, those with sites with optimal soil depth, adequate fertility and adequate soil aeration, averaged over species. Hence, the model offered an opportunity to relate changes in growing season, temperature, and rainfall patterns to changes in forest productivity (Lemieux 1961).

Booth (1990) described a technique to identify potential sites for plantation influenced by six climatic criteria: mean annual rainfall; rainfall regime; dry season length; mean maximum temperature of the hottest month; mean minimum temperature of the coldest month; and mean annual temperature. This had a close resemblance with CVP requirements and is therefore similar to the CVPI which is based on evapotranspiration, annual temperature range, mean annual precipitation, length of growing season, and mean monthly temperature of the warmest month (Paterson 1956).

Spatial distribution of productivity

Thermal regime is one basic climatic parameter used to define the agro-ecological zones. The thermal regime refers to the amount of heat available for plant growth and development during the growing period. The mean daily temperature usually defines it during the growing period. The determination of the beginning of the growing period is based on the start of the rainy season (FAO 1996).

If any region experiences severe reduction in precipitation or increase in temperature, by calculating CVPI it would be clear how much the growth rate would be affected. Thus, the index is an indicator of the climate-vegetation relationship in any region. CVPI value for Bangladesh indicates that, in some cases, such as in the western agro-ecological areas, vegetation productivity reduces. From past to present studies toward future experiments, this statement is supported.

Research has found that most of the economically important forest tree species might shift their geographical distribution slightly from the western to the eastern part of the country in the far future (2100 AD). This may be due to an altitudinal rise from the western to the eastern region. Alternatively, it may be due to the variation and sharp changes in climate variables from the last 30 to the next 90 years in the country (Rahman 2012).

Table 2 shows the CVPI value calculated for different ecosystems of former East Pakistan (present Bangladesh), which demonstrates similar result with present study. From a comparative study it can be said that CVPI values significantly increase in dry deciduous (dry Sal) forest. This may be due to the uprising effect of mean monthly maximum temperatures and precipitation.

Forests of India and Bangladesh are quite similar as the two countries are the closest neighbors in this region. Forest productivity at different eco-regions calculated from CVPI in India by Kant (2005) is listed in Table 3. This is similar to the results of the present study (Table 2)

In forestry studies, site quality is evaluated with the help of different indices. There is no single index based directly on environmental parameters that shows sufficient precision in forest management and modeling. However, wood production may be the best indicator of forest productivity, but measuring volume production is a difficult task and it is not satisfactory to use an easier method (Vanclay 1994). Paterson's regression (equation 3) could be the solution for calculating productivity in terms of wood volume using only environmental factors (Pardé 1958; Kant 2005). Paterson calculated his CVP for hundreds of points in the world (Paterson 1956), each of

Table 3. Forest productivity calculated from CVPI in India by Kant (2005).

Forests type	Productivity from CVPI
Tropical dry and moist forests	6–9 $m^3\ ha^{-1}\ yr^{-1}$
Gangetic plains	6–9 $m^3\ ha^{-1}\ yr^{-1}$
Evergreen and moist deciduous forests	9–12 $m^3\ ha^{-1}\ yr^{-1}$
Coastal belts of west and east coasts	>12 $m^3\ ha^{-1}\ yr^{-1}$
Moderately high hill range	>12 $m^3\ ha^{-1}\ yr^{-1}$

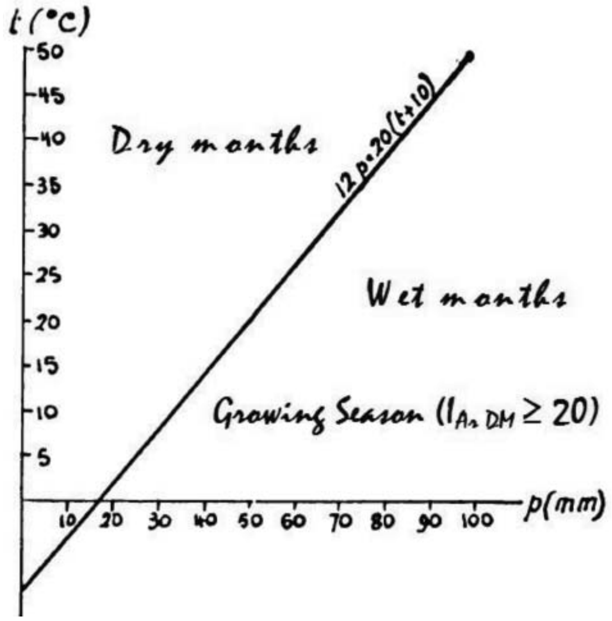

Figure 4. Growing season and aridity index by Pardé (1958).

which varies between a value of 0 $m^3ha^{-1}yr^{-1}$ to 15−16 $m^3ha^{-1}yr^{-1}$. He noted existence of strong correlation between potential productivity and envisaged production (Pardé 1958).

Temporal distribution of productivity

Temporal distribution of CVPI values were found with significant variations over the years. A rise with a peak in values was found during 1998 when there was a nationwide flood in Bangladesh due to devastating precipitation and maximum mean monthly temperatures during monsoon (Ninno et al. 2001). Thus, the relevance of vegetation productivity with respect to climate factors may be proved from yearly and even seasonal climatic events. This would be evident from Pardé's (1958) growing season (I_{Ar} DM $\geq$ 20) concept: a growing season is counted where the value of De Martonne's index exceeds or equals 20. Index value that admits to be on wet month side in Figure 4 i.e. where I $\geq$ 20; values of IAR may be included and counted as a value for G in Paterson's equation.

Conclusion

Climate is one of the important factors that influence forest growth and distribution. There are many ways to determine forest productivity in terms of climatic factors. When soil factors remain constant, climate factors such as temperature, precipitation, length of growing season, and effective sun hour become more prominent for forest growth and productivity. By assessing CVPI it is evident that both spatial and temporal variability exists in Bangladesh. From western to eastern regions, forest and vegetation productivity increases as precipitation and mean temperatures rise significantly. Productivity also changes temporally in years when there is an elevation from the normal range in precipitation and mean temperature.

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