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Climatic suitability analysis of fast growing tree species under wastelands of Uttarakhand for carbon credit

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सार – क्योटो प्रोटोकॉल एनेक्स बी देशों के लिए तथाकथित नए वनों में वृक्ष रोपित करके अथवा अलग तरीके से वनों अथवा कृषि योग्य भूमि का प्रबंधन करने (भू-उपयोग, भू-उपयोग परिवर्तन और वन माप: LULUCF) के लिए अपनी वचनबद्धता को कुछ हद तक कम करने का सुनिश्चित अवसर उपलब्ध कराता है। इन LULUCF विकल्पों की धारणा है कि प्रशमन योजना के रूप में वायुमंडल से CO_2 को हटाकर वनों में नए वृक्षों को लगाते हुए वायुमंडलीय CO_2 सांद्रता को स्थिर किया जाए। निचले दर्जे के क्षेत्रों में भूमि से कार्बन को अलग करने की अधिक क्षमता होती है; अवशिष्ट के लम्बे समय तक रहने के कारण वनस्पति के भंडारण को प्रमुखता दी जाती है और वायुमंडल में तेजी से छूटने वाले कार्बन का जोखिम कम रहता है। इस अध्ययन का मुख्य उद्देश्य सुदूर संवेदी (RS) और भौगोलिक सूचना प्रणाली (GIS) के माध्यम से तेजी से बढ़ने वाली वृक्ष की प्रजातियों को रोपित करने के लिए उजाड़ भूमि में अनुकूल स्थान का पता लगाना था। पहचाने गए थीम लेयरों की प्रक्रियाओं के ओवरले से प्राप्त जलवायु की अनुकूलता से वृक्ष की आवश्यकताओं का पता चलता है जिस पर अनुकूलता आधारित है। पहचाने गए थीम लेयरों में तापमान (अधिकतम, न्यूनतम और औसत तापमान), वर्षा और मृदा के गुण शामिल हैं। उन थेमेटिक स्तरों के आँकड़ों के साथ उनसे सम्बद्ध गुणों वाले आँकड़ों को GIS आँकड़ों में एनकोडिड किया गया। अनुकूलता मॉडल के अनुरूप उन स्तरों पर ओवरले प्रक्रिया अपनाई गई। अंकीय स्तरों का पुन: वर्गीकरण किया गया और दिए गए कुल भारों का आगे और विश्लेषण किया गया। अंत में पाँच अनुकूलता वाली श्रेणियों नामत: अत्यधिक अनुकूल, अनुकूल, साधारण रूप से अनुकूल, कम अनुकूल और अनुकूल नहीं के साथ अनुकूलता मानचित्र तैयार किया गया। प्रत्येक मानचित्र के साथ अनुकूलता मानचित्र विकसित करने के बाद GIS में प्रत्येक वृक्ष की प्रजाति को कुछ तर्कसंगत और समीकरणों के साथ अलग नम्बर दिया गया और अंतिम अनुकूलता मानचित्र तैयार किया गया। वृक्ष की प्रत्येक प्रजाति की अनुकूलता वर्ग बताने वाले अंतिम मानचित्र को अनुकूल, साधारण रूप से अनुकूल, कम अनुकूल और अनुकूल नहीं के रूप में रेखांकित किया गया। अंतिम अनुकूलता मानचित्र के अनुसार पोपलर, सफेदा और चीड़ को 631730 हे. 123290 हे. और 529810 हे. क्षेत्र में बोया जाना चाहिए जिसमें कार्बन क्रेडिट की संभावना क्रमश: 89.5 दस लाख यूरो, 11.1 दस लाख यूरो और 209.8 दस लाख यूरो होगी। अन्य प्रजातियों की तुलना में ऐकेशिया कैटेचू में वार्षिक कार्बन पृथक्करण की संभावना कम होने के कारण अपना स्थान नहीं बना पाया। निष्कर्ष स्वरूप यह कह सकते हैं कि उत्तराखंड में उजाड़ भूमि में तेजी से बढ़ने वाले वृक्षों की प्रजातियों का उपयोग करने के कारण कार्बन पृथक्करण और क्रेडिट की संभावना अधिक है।

ABSTRACT. The Kyoto Protocol provides explicit opportunities for Annex B countries to partly achieve their reduction commitments by planting new forests, or by managing existing forests or agricultural land differently (so-called Land-Use, Land-Use Change and Forestry measures: LULUCF). The presumption of these LULUCF options is that removing CO_2 from the atmosphere and to the stabilization of the atmospheric CO_2 concentration to be used by the new forests as a mitigation strategy. The degraded areas have a large potential to sequester carbon in the soil; storage in vegetation is preferable due to their longer residual time and less risk of rapid release to the atmosphere. The main aim of this study was to identify the suitable land area of wastelands for plantation of fast growing tree species through Remote Sensing (RS) and Geographic Information System (GIS). A suitability resulting from the overlay process of the identified theme layers has unique information of tree requirement on which the suitability is based. The identified theme layers include temperature (maximum, minimum and average temperature), precipitation and soil properties. Those thematic layers with their associated attribute data were encoded in GIS database. Overlay operation was performed on those layers as the suitability model assigned. The digital layers were reclassified and given weightings to be analysed further. Finally, suitability map was prepared with five suitability categories namely, most suitable, suitable, moderately suitable, less suitable and not suitable. After developing a suitability map combined to each map with some logical equations and unique number was given to each tree species in GIS and it is to come up with a final suitability map. The final map represented the suitability classes for each species delineated as suitable, moderately suitable, less suitable and unsuitable. According to the final suitability map, Poplar, Eucalyptus and Pine should be grown on 631730 ha 123290 ha and 529810 ha area and the potential of carbon credit would be 89.5 M Euro, 11.1 M Euro and 209.8 M Euro, respectively. Acacia catechu could not find the place because of its low potential of annual carbon sequestration compared to other species. It can be concluded that Uttarakhand has a lot of potential for carbon sequestration and credits, through utilization of wasteland using fast growing tree species.

Key words – Fast growing tree species, Carbon credit, GIS & RS, Wastelands, Suitability analysis.

1. Introduction

The Kyoto Protocol, drafted in 1997 and came into force in 2005, includes quantitative targets for industrial countries (the so-called "Annex B") to limit the emissions of six GHGs (CO_2, CH_4, N_2O, and three fluorinated gases) by 2008-2012 periods. In addition to reducing emissions from fossil fuel burning, the Kyoto Protocol provides explicit opportunities for Annex B countries to partly achieve their reduction commitments by planting new forests, or by managing existing forests or agricultural land differently (so-called Land-Use, Land-Use Change and Forestry measures: LULUCF). The presumption of these LULUCF options is that removing CO_2 from the atmosphere and to the stabilization of the atmospheric CO_2 concentration, to be used by the new forests (so-called carbon plantations) as a mitigation strategy. Thus land-use changes that drive losses in biodiversity should be prevented. The Kyoto Protocol has resulted in several studies, estimating the sequestration potential in plantations. Other studies suggest that land-based mitigation could be cost-effective compared to energy-related mitigation options, and could provide a large proportion of the total mitigation (Updegraff *et al*., 2004). The degraded land have a large potential to sequester carbon in the soil; storage in vegetation is preferable due to their longer residual time and less risk of rapid release to the atmosphere (Lal, 1999). This can only be achieved through afforestation or reforestation or plantation in such areas. Tree growth serves as an important means to capture and store atmospheric carbon dioxide in vegetation, soils and biomass products (Makundi and Sathaye, 2004).

In an increasing carbon constrained world, with carbon trading growing into a billion Dollar trade, the Kyoto Protocol's Clean Development Mechanism paves way for collaboration between developed and developing countries in stabilizing atmospheric greenhouse gas emissions to a level that will prevent dangerous interference with the atmosphere's climatic cycle. Carbon credits are a key component of national and international attempts to mitigate the growth in concentration of GHGs. One carbon credit is equal to one ton of carbon dioxide or in some markets carbon dioxide equivalent gases. Carbon trading is an application of an emissions trading approach. Faster growing species, will accumulate carbon faster, thus increasing the amount of carbon credits; however, having diverse carbon crops is not only more ecologically sound, but will bring other benefits as well as buffer from losses due to disease or pests. As the trees grow older, they are able to sequester more carbon up to a certain point, and then it levels off before declining.

Remote Sensing and GIS have shown great potential in Land suitability mapping and monitoring, due to its advantages over traditional procedures in terms of cost and time effectiveness in the availability of information over larger areas. Since any suitability analysis requires use of different kinds of data and information (soil, climate, land use, topography, etc.), the geographic information system (GIS) offers a flexible and powerful tool than conventional data processing systems, as it provide a means of taking large volumes of different kinds of data sets for manipulating and combining the data sets into new data sets which can be displayed in the form of thematic maps (Marble *et al*., 1984; Foote and Lynch, 1996). The topographic characteristics, the climatic conditions and the soil quality of an area are the most important determinant parameters of the land suitability evaluations.

The present study aimed to use GIS & RS to classify the climatic suitability of fast growing tree species under wastelands of Uttarakhand for carbon credit.

2. Data and methodology

The overall methodology for Suitability analysis of fast growing tree species in Uttarakhand for wastelands is presented in Fig. 1.

2.1. *Study area*

The state of Uttarakhand which is surrounded by Himachal Pradesh in the north-west and Uttar Pradesh in the south and sharing its international borders with Nepal and China has been considered in the present study. This area is located between latitude 28º43' N and 31º27' N and longitude 77º34' E and 81º02' E. The different geo-physical and climatic parameters *viz*., precipitation, temperature and soil type were used for identifying suitable areas for fast growing tree species.

2.2. *Soil*

Soil texture is one of the most important properties of soil because it indicates the physical behaviour of soil. Knowledge of soil texture is extremely important in determining the suitability of land for the productivity of

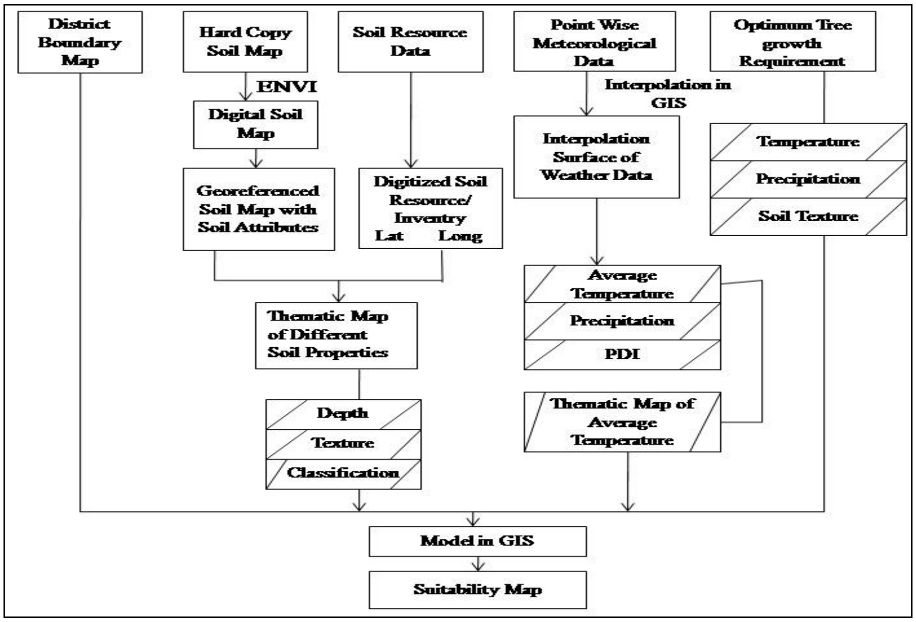

Fig. 1. Flow diagram of the method for plantation suitability assessment

different crops. It influences the various properties of soil such as structure, water holding capacity, cation exchange capacity, organic matter content, soil aeration etc. Only soil texture has been considered in the present study, as inclusion of too many soil parameters in the suitability analysis will make the process complicated. Moreover, the range of most of the soil parameters is within the optimum limit in Uttarakhand especially for perennial plants like Poplar, Willow, Eucalyptus etc. which can be grown in diverse set of soil conditions. Land slope has also not been included in the present study as terracing is in practice in Uttarakhand, which nullifies the effect of slope. Also slope is least important in case of trees, which grow well at all slopes as witnessed by thick forest cover across the state of Uttarakhand. The soil information and maps of the region were acquired from NBSSLUP, Nagpur. Entire state of Uttarakhand is covered in two maps at a scale of 1:500000. The maps were scanned using roller scanner and were mosaicked (combined) using the pixel base algorithm embedded in ENVI image processing software after rotating, resizing and contrast enhancement. The mosaicked map were geo-referenced with existing georeferenced district boundary map using map to map registration option available in ENVI image processing software, after collection of ample Ground Control Points (GCPs). The registered raster soil map was exported in imagine image (.img) compatible format so that it could be directly viewed in GIS software (ArcView 3.2a). The map was imported in ArcView software and soil polygons were digitized on line. The soil unit boundaries of the map were digitized very carefully using the polygon feature. Then the soil attribute data were added to the project. The soil attribute table comprised of different columns of fields like surface form, parent material, soil depth, mineralogy, particle size, calcareous, soil temperature, soil reaction, drainage, surface texture, slope class, erosion class, salinity, surface stone, flooding etc.

2.3. *Climatic data*

The data of all weather stations falling within the geographical boundaries of Uttarakhand were collected. Additionally, the data of meteorological observatories of adjoining states of Uttarakhand were also used in the present study. Data collected from different weather stations which located in Uttarakhand like VPKAS Almora, ARIES Nainital, DEBER Haldwani, CRC Pantnagar, College of Forestry and Hill Agriculture, Ranichauri, FRI Dehradun and data of some stations covered in UPROBE project of IIT, Roorkee were also considered, while some other stations, data were taken from published IMD periodicals. The complete list of stations of Uttarakhand with number of years, mean and CV% of available parameters has been appended in the Table 1**,** while the climate normal's of other stations computed by IMD on the basis of thirty years weather data and published in IMD periodicals have been presented in Table 2. The geocordinates of all the weather stations were recorded with the help of GPS or were collected from literature / published maps. Weather data with geocordiantes were stored in a table and saved as a txt file. Text file was added in GIS environment and thereafter was added to GIS view using "add event theme" option. The "spatial extension" was loaded in order to use the interpolation functions available in GIS environment. Inverse Distance Weightage (IDW) interpolation technique was used to construct the thematic layers of the different weather

TABLE 1

Climatic normals with no. of years and CV% of different stations of Uttarakhand

Station Name	Max. Temp. (°C)		Min. Temp. (°C)		Aver. Temp. (°C)		Rainfall (mm)		No. of Years
	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	
Almora	23.0	4.4	12.8	4.8	17.9	3.5	1197.1	17.4	5
Champawat	23.0	4.5	10.6	10.3	16.8	5.4	1343.2	17.9	5
Chinyalisaur	28.4	5.5	12.3	5.1	20.3	5.3	821.3	16.9	5
Jwalapur	30.1	3.4	19.2	3.5	24.7	3.1	896.5	19.3	5
Kotdwar	31.1	2.5	23.2	4.5	27.0	3.8	1227.8	13.7	5
Mussoorie	19.6	2.8	11.3	3.5	15.4	1.2	1603.0	18.2	5
Nainital	22.2	4.9	11.6	6.1	16.9	2.5	1753.7	19.1	5
Shantipuri	29.1	4.2	17.9	6.0	23.5	1.9	1156.8	20.3	5
Sitarganj	27.7	3.6	16.5	3.5	23.2	7.8	1358.1	16.9	5
Srinagar	18.2	4.1	17.0	2.5	17.6	3.2	934.4	17.6	5
Ukhimath	15.6	3.4	12.6	4.5	14.1	2.7	1730.8	14.7	5
Ranichauri	19.9	2.4	9.8	6.6	14.9	3.2	1146.4	22.4	11
Pantnagar	29.5	2.2	16.9	2.0	23.2	1.6	1454.2	22.4	30
Roorkee	30.1	2.4	17.3	4.0	23.7	2.5	985.6	22.7	30
Dehradun	27.8	1.8	15.4	4.2	12.4	7.7	2196.9	19.3	80

TABLE 2

Climatic data normals of different stations located in Uttarakhan and adjoining regions

Station Name	State	Latitude	Longitude	Elevation	Tmax	Tmin	Tav	Rainfall
Najibabad	UP	29.61	78.38	270	30.6	16.9	23.7	1209.8
Meerut	UP	29.02	77.63	222	31.4	17.6	24.5	901.0
Manali	HP	32.27	77.70	2039	20.0	6.1	13.1	1459.2
Chandigarh	HR	30.73	76.88	347	30.4	16.5	23.4	1058.6
Bareilly	UP	28.36	79.40	173	31.6	18.8	25.2	1071.9
Ambala	UK	30.38	76.76	272	31.1	17.6	24.3	946.1
Tehri	UK	30.40	78.48	1950	29.3	14.8	22.0	962.0
Shimla	HP	31.10	77.16	2202	17.3	9.8	13.6	1412.2
Mukteshwer	UK	29.47	79.65	2311	18.3	9.0	13.6	1296.5

parameters. Interpolated weather data provides values of weather parameters on flat surface, however the topography of Uttarakhand is highly variable. Therefore weather surface was corrected using Digital Elevation Model (DEM) of Uttarakhand. DEM provides a digital representation of a portion of the earth's surface terrain over a two dimensional surface. The DEM was used for constructing temperature surfaces keeping in view the environmental lapse rate. The environmental lapse rate which describes that with increasing elevation by 1 km the temperature will decrease by 6.5 ºC, was used to correct the interpolated temperature surface using following equation.

$$T_{cor} = T_{int} - \left[\left(Alt_{act} - Alt_{int} \right) \times \frac{6.5}{1000} \right]$$

where, T_{cor} = Temperature corrected in °C,

T_{int} = Temperature interpolated in °C,

TABLE 3

Soil and climatic requirement for fast growing tree species

Tree species	Max. temp. (ºC)	Min. temp. (ºC)	Optimum temp. (ºC)	RF (mm)	Soil type
Poplar	30-40	5-10	15 to 25	1000-1400	Loamy Clay
Willow	30-40	5-10	15 to 26	600-1000	Loamy
Eucalyptus	22-42	-2 to 19	10 to 27	500-3000	All type soil
Pine	27-38	2	12 to 17	250-2000	All type soil
Acacia catechu	39	-1	32 to 39	500-2000	Sany clay, loamy, sandy

Alt_{act} = Actual altitude in m and

Alt_{int} = Interpolated altitude in m

2.4. *Soil and climatic requirement of fast growing tree species*

The optimum climatic requirement (*i.e.* maximum, minimum and optimum temperature, rainfall) and soil type for fast growing tree species are essential in order to check the spatial suitability of plant in a given region. This information was collected from the published literatures and is presented in Table 3.

2.5. *Computation of PDI*

We used the Precipitation Distribution Index developed by Nain *et al.* (2010). The PDI represents the availability of moisture for the deep rooted plant in a year. The precipitation distribution index (PDI) was calculated with the help of the following formula:

$$\text{PDI} = \frac{\sum(\text{Month with value 1})}{12}$$

where, PDI = Precipitation Distribution Index

1 = the value of a particular month when the ratio of P/PET is > 0.3, the value of month is 0 when the ratio between P/PET is < 0,

P = Precipitation (mm) and

PET = Potential Evapotranspiration (mm).

PET was calculated using Thornthwaite method. The formula was found suitable for calculation of PET on monthly basis by different researchers (Michael, 2008) in the various parts of the world. Thornthwaite proposed the following formula for monthly potential evapo-transpiration:

$$e = 1.6\left(\frac{10*t}{I}\right)^a$$

where,

e = unadjusted potential evapo-transpiration (cm/month) (month of 30 days each and 12 hours day time),

t = mean air temperature (ºC),

I = annual or seasonal heat index, the summation of 12 values of monthly heat indices (*i*) when,

$$i = \left(\frac{t}{5}\right)^{1.514}$$

a = an empirical exponent computed by the equation,

a = $0.0000006751*(I^3)-0.0000771*(I^2)+0.01792*I+0.49239$.

The unadjusted values of "e" are corrected for actual day light hours and days in a month. For daily computation, the formula is modified as:

$$\text{PET} = \left(\frac{\text{k} \times \text{e} \times 10}{\text{No. of days in month}}\right) \text{mm/day}$$

where,

k = adjustment factor for which table values are given by Michael (1978).

The PDI was computed on point data and later the spatial surface covering entire state of Uttarakhand was generated by

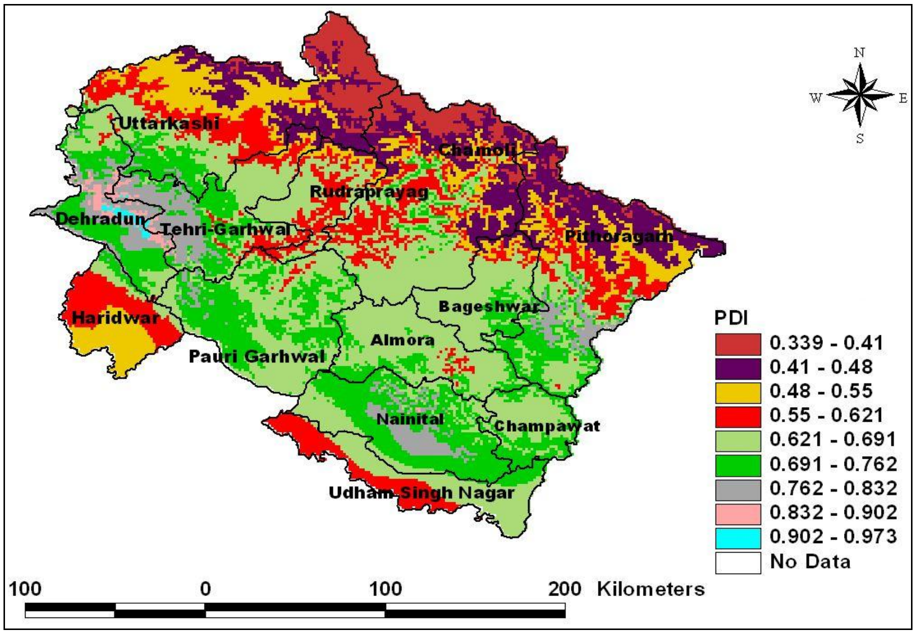

Fig. 2. Thematic map of PDI over Uttarakhand

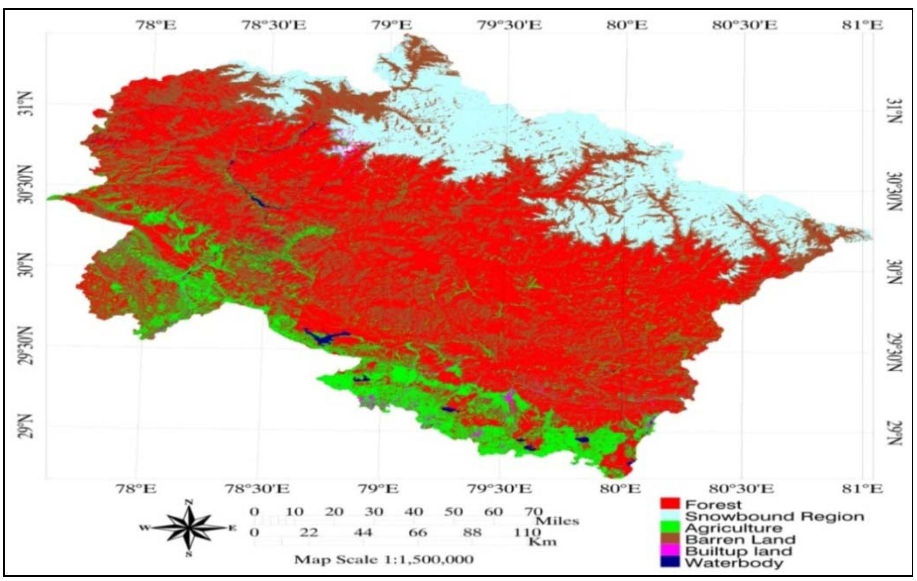

Fig. 3. Land use and land cover map of Uttarakhand

developing a relationship between point precipitation and point PDI and later applying the model on the precipitation surface (Fig. 2). PDI surface was divided in 3 classes, which are more suitable, moderatly suitable and less suitable (Table 4). If PDI value is high, then it more suitable for planting trees and if it is low then it is less suitable.

2.5. *Land use and land cover map*

There are six land use/land cover patterns found in Uttarakhand, *i.e.*, forest, agricultural land, built-up land, barren land, water body and snow bound region. Out of the total geographical area (5336 km^2) of Uttarakhand, most of the areas especially hills are covered with forest (41.41%). Agricultural area is about 10.18% of total geographical area. Most of the agricultural land falls under Tarai and Bhaber region. Barren land, built-up land and water body are about 29.98%, 0.55% and 0.56% respectively of total geographical area. The total snow covered area of Uttarakhand is about 17.3% (Fig. 3).

2.6. *Model for suitability analysis*

Suitability model was developed using model builder module available in Arc-View 3.2a GIS. The interpolated data related to climate and soils were converted in to raster format. The reclass function was added and reclasses of data was done. Then all these reclass data were combined to the weighted overlay function and a weighted overlay model was developed. Thereafter model was run and suitability map was generated. Weights given to the different parameters are shown in Table 5 on the basis of their effect on growth of trees. A value has been assigned to the different ranges of parameters on the basis of optimum, minimum and maximum range of parameter as mentioned in the Table 3. The area with value of parameter less than minimum value required by plant and higher value of the parameter than the maximum required by the plant were restricted as no proper growth of fast growing tree species is possible in those regions. The optimum range has been assigned value of three (3), while sub-optimum range has been assign value of two (2) and sub-suboptimum range has been assigned value of one (1). A suitability map with 4 classes: most suitable, suitable, moderately suitable, less suitable and not suitable was generated. Most suitable class was found when all parameters weightage values are highest, while other classes were generated on basis of descending values.

2.7. *Suitability map for different fast growing tree specie*

The suitability zones for different tree species (Poplar, Willow, Eucalyptus, Pine, and Acacia Catechu) were formed on the basis of requirements of weather and soil. Entire area of Uttarakhand was divided into five classes, *viz*., most suitable, suitable, moderately suitable, less suitable and not suitable. The weightage was assigned to different soil and weather parameter depending upon requirement. Highest weightage was given to optimum temperature and lowest weight was given to minimum temperature and soil types. Suitability zones were formed using the Model Builder Extension available in ARC-View 3.2a.

2.8. *Final suitability map of fast growing tree species*

After developing suitability map combined to each maps with some logical equations, an unique number was given to each tree species (Table 6) in GIS and prepared a final suitability map. The final map represented the suitability classes for each species, delineated as most suitable, suitable, moderately suitable, less suitable and unsuitable.

TABLE 4

Table of PDI with suitability classes

S. No.	PDI range (>0.3)	Suitability classes for tree plantation
1.	0.33-0.55	Less Suitable
2.	0.55-0.75	Moderately suitable
3.	0.75-0.98	More suitable

TABLE 5

Weightage percentage given to the parameters

S. No.	Input Theme	% Info
1.	Average Temperature	40
2.	Minimum Temperature	5
3.	Precipitation	20
4.	PDI	25
5.	Soil Texture	10

2.9. *Wastelands of Uttarakhand with respect to suitability of fast growing tree species*

The area of forest, agricultural land, water bodies and buildings are discarded in land use and land cover image and remaining classes like non-agriculture and fallow lands were considered as a waste land and obtained a wasteland map. This wasteland map was superimposed on suitability map of fast growing tree species and the zones of Uttarakhand with respect to suitability of fast growing tree species were delineated.

2.10. *Potential of carbon credit*

Data on annual sequestration potential of carbon (C_{seq}) by the fast growing tree species suitable to be grown in this area was collected from published literature. Highest annual sequestrated potential of carbon was by Pine (7 t/ha) followed by Poplar (2.54 t/ha), Eucalyptus (1.62 t/ha) and lowest in *Acacia catechu* (1.5 t/ha) (Ganguli, 2008). The collected value of C_{seq} was multiplied with the most suitable, suitable and moderately suitable wasteland areas to obtain the total possible amount of carbon sequestration by these different species. The carbon credit that can be earned out of wasteland utilization was also computed based on the international carbon pricing. The carbon trading prices however tentative entities and are more or less subjected to change according to the fluctuations in the market. Hence the carbon credit achieved under any CDM project is liable to change. The current market prices of 1 ton of CO_2 per ha is Euro 15.24, which is subject to change with time according to market (http://www.carbonpositive.net/ viewarticle.aspx? article ID = 1990). Maximum carbon credits are achieved with highest biomass, which

TABLE 6

Unique numbers and combination of each species

Species	Code	1^{st} Tier	2^{nd} Tier	3^{rd} Tier	4^{th} Tier	5^{th} Tier
Poplar	1	1	1 & 5 = 6	1, 5 & 10 = 16	1, 5, 10 & 20 = 36	1, 5, 10, 20 & 40 = 76
			1 & 10 = 11	1, 5 & 20 = 26	1, 5, 10 & 40 = 56	
			1 & 20 = 21	1, 5 & 40 = 46	1, 5, 20 & 40 = 66	
			1 & 40 = 41	1, 10 & 20 =31	1, 10, 20 & 40 = 71	
				1, 10 & 40 = 51		
				1, 20 & 40 = 61		
Willow	5	5	5 & 10 = 15	5, 10 & 20 = 35	5, 10, 20 & 40 = 75	
			5 & 20 = 25	5, 10 & 40 = 55		
			5 & 40 = 45	5, 20 & 40 = 65		
Eucalyptus	10	10	10 & 20 = 30	10, 20 & 40 = 70		
			10 & 40 = 50			
Pine	20	20	20 & 40 = 60			
Acacia	40	40				

TABLE 7

Potential of carbon sequestration and carbon credit of different fast growing tree species

Species	Annual rate of Carbon Sequestration (tC/ha)	Area (ha)	Potential of Carbon Sequestration (MtC)	Potential of CO_2 reduction ($MtCO_2$)	Potential of Carbon Credit (M Euro)
Poplar	2.54	631730	1.60	5.87	89.5
Willow	1.80	74240	0.13	0.49	7.5
Eucalyptus	1.62	123290	0.20	0.73	11.1
Pine	7.1	529810	3.76	13.77	209.8

consequently means a higher CO_2 mitigation potential. CO_2 mitigation was estimated by multiplying the annual carbon stock with 3.66 (conversion factor of C to CO_2).

3. Results and discussion

3.1. *Suitability of wasteland for fast growing tree species*

The map representing the suitability classes of wasteland for each species, delineated as most suitable, suitable and moderately suitable zones in respect to the different tree species is presented as (Fig. 4).

(*i*) *Most suitable* : An area of current wastelands of 8634.2 km^2, which accounts for 16.1% of the total geographical area of the Uttarakhand was found to be most suitable for different tree species. In this zone currently Poplar covers 1414.2 km^2 (2.6%), Willow 99.2 km^2 (0.2%), Poplar and Willow 1248.2 km^2 (2.3%), Eucalyptus 605 km^2 (1.1%), Willow & Eucalyptus 343.5 km^2 (0.6%), Poplar, Willow and Eucalyptus 2958.2 km^2 (5.5%), Poplar, Willow and Pine 366.4 km^2 (0.7%), Poplar, Willow, Eucalyptus and Pine 1599.4 km^2 (3%).

(*ii*) *Suitable* : This class covers 3362.9 km^2 areas of total wastelands, which constitutes 6.3% of the total geographical area of Uttarakhand. In this class Eucalyptus covers 599.3 km^2 (1.1%), Pine 66.8 km^2 (0.1%), Eucalyptus and Pine 250 km^2 (0.5%), Eucalyptus and *Acacia catechu* 28.6 km^2 (0.1%), Poplar, Eucalyptus and *Acacia catechu* 93.5 km^2 (0.2%), Poplar, Willow, Eucalyptus and *Acacia catechu* 120.2 km^2 (0.2%), Poplar, Willow, Pine and *Acacia catechu* 9.5 km^2 (0.04%), Eucalyptus, Pine and *Acacia catechu* 13.4 km^2 (0.05%), Poplar, Eucalyptus, Pine and *Acacia catechu* 42 km^2 (0.15%), Poplar, Willow, Eucalyptus, Pine and *Acacia catechu* 2139.5 km^2 (4%), respectively.

(*iii*) *Moderately suitable* : This zone covers 1593.6 km^2 area of total wasteland, which is 3% of the total geographical area of Uttarakhand. In this zone willow

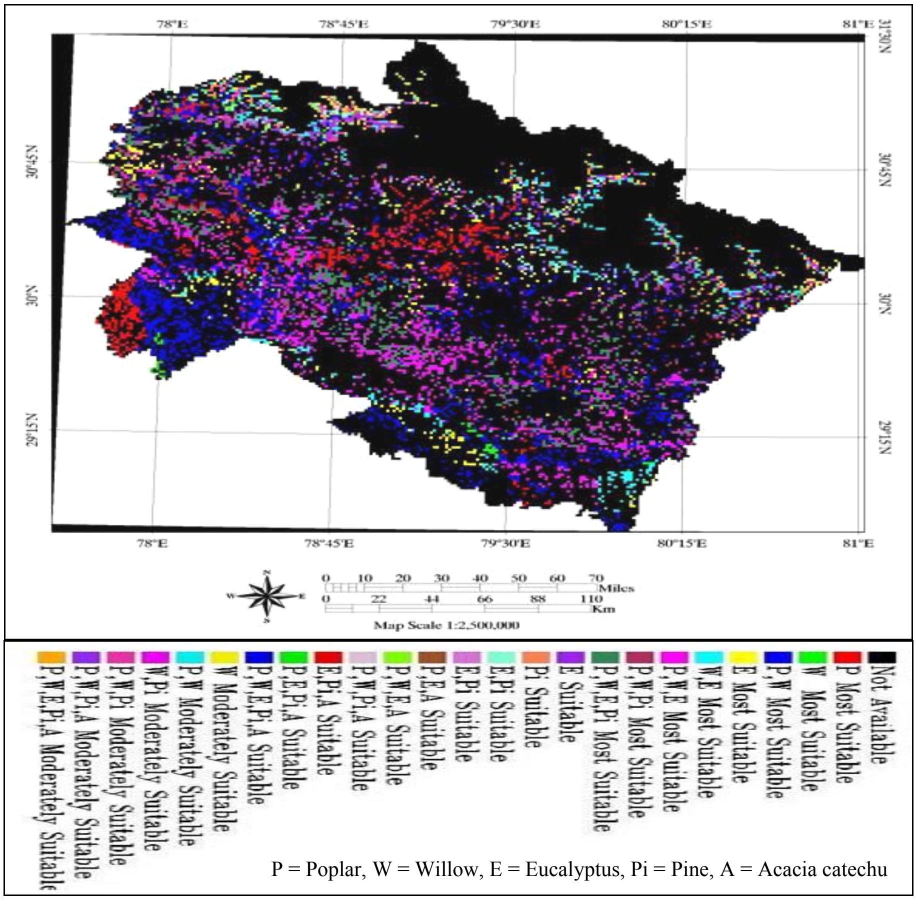

Fig. 4. Wasteland Suitability Map of Fast Growing Tree Species in Uttarakhand

covers 299.6 km^2 (0.6%), Poplar and Willow 603.1 km^2 (1.1%), Willow and Pine 34.4 km^2 (0.1%), Poplar, Willow and Pine 297.7 km^2 (0.6%), Poplar, Willow, Pine and *Acacia catechu* 164.1 km^2 (0.3%), Poplar, Willow, Eucalyptus, Pine and Acacia catechu 194.7 km^2 (0.4%).

Chowdhury (1992) developed the 54 ha wasteland in Purulia District (W. B.), through a variety of plantation models, aiming at an ecological and economical rehabilitation of the large local population in the immediate vicinity of the area. Quick growing or early yielding species were chosen in his plantation model. Three plantation models were adopted: (1) Cashew plantation with intercropping of sabai grass, (2) Bamboo plantation and (3) *Acacia auriculiformis* and Eucalyptus plantation. Srivastava (1992) also used energy plantation to develop 8 million ha wastelands in Gujarat.

3.2. *Potential of carbon credit by Fast Growing tree species in Uttarakhand*

Table 7 shows the potential of carbon sequestration and carbon credit of different fast growing species. The analysis is based on the criteria that the tree which can sequester more carbon per ha per year should be preferred over other species, brought out that Poplar should be grown on 631730 ha area. The potential of carbon sequestration by poplar was estimated to be 1.60 MtC (5.87 $MtCO_2$) with carbon credit of 89.5 M Euro. Similarly Willow should be grown on 74240 ha area, which will sequester 0.13 MtC (0.49 $MtCO_2$) with carbon credit of 7.5 M Euro. Eucalyptus should be grown on 123290 ha area, which will sequester 0.20 MtC (0.73 $MtCO_2$) and will earn carbon credit of 11.1 M Euro. Pine may be grown on a larger area spreading over 529810 ha with a carbon potential of 3.76 MtC (13.77 $MtCO_2$) and can fetch 209.8 M Euro as carbon credit. *Acacia catechu* could not find the place because of its low potential of annual carbon sequestration compared to other species.

Potential carbon sequestration and carbon credit analysis only show the possibility of carbon sequestration, if wastelands are utilized for plantation. Utilization of wasteland is indeed a difficult task because it requires sufficient amount of funds for plantation and maintenance. Funds would be required for further selection of species, labour, transportation etc. for their plantation. It may not be possible to utilize the entire wastelands of Uttarakhand, because of many difficulties, such as boulders or stones, while some land is in deep valley therefore can't be used for plantation and economical uses. However, large amount of area is unused and available as waste land, any portion of the wasteland that has utilized for fast growing tree species will be beneficial for livelihood, environment, and socio-economic purpose in the state.

Advocating plantation to sequester carbon will certainly not bring overwhelming response. However, some sort of incentives in term of carbon credit may definitely produce tremendous results. Sedjo (1989) observed that annual atmospheric increase of carbon is 2.9 Bt. To sequester this amount 465 million ha new plantation will be required at a cost of US$ 372 billion. Khanjuria and Chauhan (2003) reported that a project to restore 10,000 ha of degraded community land in Handia Forest Range of Madhya Pradesh, India has been estimated to earn US$ 300,000. The sequestered carbon under the project can be sold as "Carbon Credit" at the global rate of US$ 16-20 per tonne. They further reported that in Punjab 15% of geographical area should be under forest trees that equals 7.5 lac hectares. If this forest will give 10 m^3 of increment per annum per hectare then 7, 50,000 m^3 woods will be added annually. This will fix approximately 1.5 million tonnes of carbon worth US$ 20-25 million and remove 2.5 million tonnes CO_2 from atmosphere. Benitez and Obersteiner (2006) stated that afforestation and reforestation in next 20 year will sequestrate cumulative carbon of 125 MtC and 337 MtC by 2012 and 2020, respectively and explained that the net benefit could amount up to US$ 2.3 billion in 2020 using carbon price $20/tC.

4. Conclusion

In the light of results summarized above, it can be concluded that Uttarakhand has a lot of potential for carbon sequestration and credits through utilization of wastelands by using them for fast growing tree species. Pine has highest potential for 3.76 MtC (13.77 $MtCO_2$) sequestration and 209.8 M Euro carbon credit followed by Poplar having potential of 1.60 Mt, storage of C (5.87 $MtCO_2$) sequestration and carbon credit of 89.5 M Euro. Analysis revealed that Eucalyptus is having a potential of 0.20 MtC (0.73 $MtCO_2$) sequestration and carbon credit of 11.1 M Euro. The analysis for Willow exhibited a plantation of 0.13 MtC (0.49 $MtCO_2$) sequestration potential and carbon credit of 7.5 M Euro. Pine is best for carbon sequestration in the long rotation while, but Poplar Willow and Eucalyptus are best for short rotation. Adopting such a tree plantation programme for carbon accounting would be the best driver for utilization of wasteland in a sustainable land-use system, which will also help restore the degraded land and provide income to rural communities.

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