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To cite this article: A I Kurbatova and A M Tarko 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **272** 022003

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# Impact of Global Climate Change on the Dynamics of Carbon Balance of Plant Communities in South Asia

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**Abstract.** Assessment of the status of ecosystems experiencing anthropogenic impact is based on the ability of plant communities in such ecosystems to withstand these disturbances or to mitigate their effects fast enough. The aim of this paper is to analyze the impact of global climate change on carbon balance of plant communities of South Asia. To achieve this objective, the spatial model of global carbon cycle developed by the Computing Center of the Russian Academy of Sciences (RAS CC) was used to calculate the impact of industrial CO<sub>2</sub> emissions as well as the main causes of carbon losses in the investigated region (deforestation and soil erosion) on the dynamics of carbon accumulation in the humus and phytomass of forest ecosystems. India was selected as a model country to assess and compare the compensatory functions of plant communities. On the basis of the spatial mathematical model of the global carbon cycle in the biosphere, changes in CO emissions as a result of burning fossil fuels, deforestation, and soil erosion associated with improper land use in South Asia were estimated. The impact of deforestation and soil erosion on climate change in South Asia is forecast up to the year 2060. A comparison of regulatory functions of different types of plant communities was performed for the study area. The calculations data revealed some regularities occurring in the ecosystems of South Asia under the impact of CO<sub>2</sub> emissions, deforestation, and soil erosion due to improper land use. Mathematical modelling has shown the dependence of growth of humus and phytomass of vegetation on the amount of CO<sub>2</sub> in the atmosphere. Quantitative forecast of the dynamics of the ecosystem characteristics of plant communities depending on the growing region has been performed.

## 1. Introduction

The South Asian region has huge potential of reproducible resources. However, the region is characterized by the unprecedented scale of poverty and economic dependence, where the negative nature of the relationship between environmental degradation and impoverishment of the population is mediated by the effect of the demographic factor on these processes. For example, in India, 175 million hectares out of 329 million hectares of the country are subject to the processes of soil erosion, water logging and salinization. This was largely the result of "green revolution", which was carried out without considering the adverse environmental impacts of intensifying agricultural production. During the period from 2003 to 2005, the forest area of India was reduced by 728 km<sup>2</sup> [1]. Deforestation in India, as well as in other countries of the region, is associated with many factors, such



as overgrazing, the conversion of forest areas into agricultural land, urbanization, development projects and the use of forests as fuel. Logging poses the greatest threat to the conservation of forests, as it covers 235 million m<sup>3</sup>, which exceeds the rates of “sustainable logging” of 48 million m<sup>3</sup> ensuring the regeneration of the forest. In Nepal, the deforestation combined with the plowing of steep slopes leads to catastrophic increase in the soil erosion rates. Mountain desertification is particularly dangerous because it entails a disruption of the normal cycles of recovery of renewable natural resources in the vast surrounding areas. Violation of the ecological balance of the Himalayas has a detrimental effect on the environment of the entire South Asian subcontinent. Massive deforestation in the Himalayas is accompanied by more natural disasters in the Indo-Gangetic plain – the world's largest area of concentration of the rural population, as well as in the basin of the Brahmaputra. For Bangladesh, Pakistan and Bhutan degradation and soil erosion, deforestation and excessive growth of pastoralism are also current environmental issues. South Asia covers a large area of lands of various categories (Tab.1). In the region a significant amount of forest land is dedicated to arable and agricultural lands, making a negative contribution to carbon dioxide emissions.

**Table 1.** Area of different land categories of the South Asian region.

Country /Area S (Mha)	Total	Dry land	Agricultural land	Arable land	Grazing land	Woods and forests
Bangladesh	14,4	13	9	8,1	0,6	1,3
Bhutan	4,7	4,7	0,5	0,15	0,4	3
India	328,7	297,3	180,8	161,8	11,1	64,1
Nepal	14,7	14,3	4,2	3,1	1,7	3,9
Pakistan	79,6	77,1	25,1	21,5	5	2,4
Sri Lanka	6,6	6,5	2,4	0,9	0,4	1,9
Total	448,7	412,9	222	203,5	19,2	76,6

Most soils of South Asia are characterized by extremely low reserves of soil organic matter, fluctuating in the range of 8-10 g/kg [3]. Loss of organic matter leads to other soil degradation processes as well, including changes in its structure and aggregation, metabolic processes, and reduction in the cationic exchange capacity, which adversely affects crop yields [4].

Due to the fact that the plant formations play a significant role in absorbing carbon dioxide, the data were analyzed according to CO<sub>2</sub> emissions in the countries of study region. According to numerous research works [5; 6; 7; 8] the last decades have witnessed increase amounts of carbon dioxide emissions. Table 2 shows the emissions from fossil fuels in the study region for the period 1990-2009. The carbon balance of ecosystems is an integral indicator of their functioning, as it reflects the intensity of the basic processes occurring in living systems – photosynthesis and respiration, biological production of its destruction and consequently of all other ecosystem functions [9].

**Table 2.** The average emission of CO<sub>2</sub> from fossil fuels and annual growth in South Asia for the period 1990-2009.

Country/Region	Average value of emission (GT C year <sup>-1</sup> ) 1990-2009	Annual growth (% year <sup>-1</sup> ) 1990-2009	Average value of emission (GT C year <sup>-1</sup> ) 1990-1999	Annual growth (% year <sup>-1</sup> ) 1990-2009	Average value of emission (GT C year <sup>-1</sup> ) 2000-2009	Annual growth (% year <sup>-1</sup> ) 2000-2009
Bangladesh	8,207	6,2	5,638	6	10,775	6,1
Bhutan	0,113	7,8	0,072	11,4	0,154	8,5
India	319,81	4,7	247,44	5,6	392,18	5,3
Nepal	0,702	5,6	0,514	13,8	0,889	2,3
Pakistan	29,986	4,1	23,019	4,7	36,932	5,7
Sri Lanka	2,368	5,8	1,629	8,9	3,107	2,2
Total	361	5,7	278	8,4	444	5

As can be seen from Table 2, total volume of emissions has increased from 213 GT C yr<sup>-1</sup> in 1990 to 573 GT C yr<sup>-1</sup> in 2009.

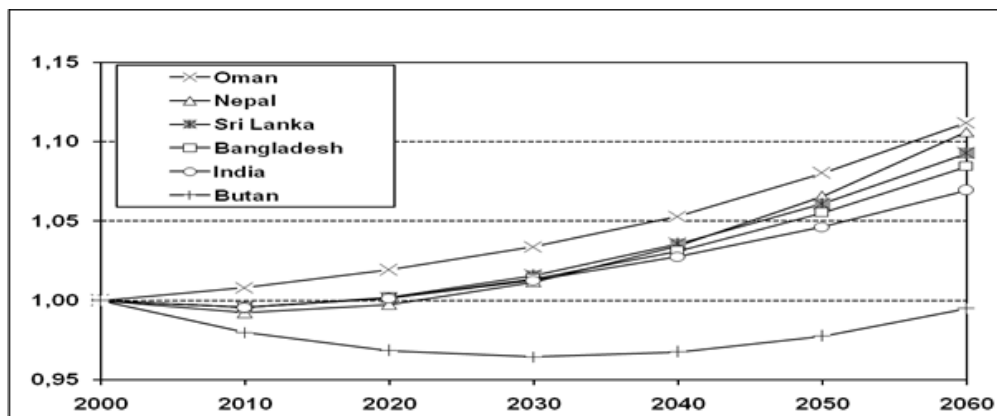
## 2. Materials and methods

The impacts of global warming and other anthropogenic factors on the ecosystems of South Asia were considered in this study. The spatial model of the global carbon cycle developed by A. M. Tarko (RAS CC) was used in estimating the emission for the period 1860-2060. The model takes into account the fact that industrial CO<sub>2</sub> emissions, deforestation and soil erosion occurring on certain territory are mixed in the latitudinal direction within about two weeks, and in the meridional direction within 2-3 months. Therefore, each country or region at the same time experiences the effect of climate change depending on cumulative emissions of other countries worldwide. Consequently, to calculate climate changes occurring due to global warming in one region or country, it is essential to apply a global spatial model of carbon cycle, taking into account the total CO<sub>2</sub> emissions of all countries of the world since the industrial period (usually the year 1860 is taken as the beginning of the anthropogenic period in models of the global carbon cycle). In the global spatial model of carbon cycle of the Russian Academy of Sciences Computational Center in the biosphere the land surface was partitioned into cells of 0,5° x 0,5° (approximately 50 km x 50 km) on the geographic grid, which is also implemented using computer. The model describes the processes of growth and decay of vegetation, accumulation and decomposition of the humus in terms of carbon exchange between the atmosphere, plants and humus soil in each cell of the land [10]. The model variables are the quantity of carbon in the phytomass of terrestrial vegetation and soil humus in each cell of the applied splitting and the number of carbon in the atmosphere as CO<sub>2</sub>. John Olson's classification of ecosystem types taking into account not only natural ecosystems but agricultural ones as well was considered [11]. In the carbon balance of the country the absorptive capacity of CO<sub>2</sub> should be evaluated as an integral part of the global balance taking into account the contribution not only of forests but other biomass too (grassland, farmland, wetlands and tundra) [12]. The climate in each cell is characterized by average annual air temperature on the earth's surface and the amount of precipitation for the year, taking into account the greenhouse effect of carbon dioxide of the atmosphere. Depending on the amount of carbon in the atmosphere (the greenhouse effect) the temperatures and precipitation for each cell of land are calculated with the use of the climate model of general circulation of the atmosphere and ocean [13]. The model is supplemented by the model of the carbon cycle in the system "atmosphere – ocean".

The dynamics of the biosphere was simulated for the period 1860 - 2060. The following baseline scenario was adopted: anthropogenic CO<sub>2</sub> uptake in the atmosphere begins in 1860 by industrial emissions of CO<sub>2</sub> from combustion of fossil organic fuels, deforestation and soil erosion; after 1950, cutting of trees started taking place and the subsequent destruction of tropical forests occurred. As a result, during this period, the tropical forests coverage was reduced annually by 0.6 % [10] and the corresponding amount of CO<sub>2</sub> from decomposed organic matter of the wood emitted to the atmosphere. Soil erosion occurs due to improper agricultural exploitation of land, while the corresponding amount of CO<sub>2</sub> from decomposition of diminished humus gets into the atmosphere. Since 1860, the erosion rate has been taken equal to 0.15% per year [10;14]. Various scenarios take into account different changes of deforestation and erosion in time. The area of deforestation and erosion is set by the corresponding spatial distributions for each cell of the model. Data on the industrial CO<sub>2</sub> emissions for the world and all countries in 1751-2010 are taken from literature sources. The main objective of this paper is to study regional impacts of global warming and land use in South Asian countries with special emphasis on India as a model area. To achieve that, changes of biomass, humus and the total amount of carbon emitted from industrial sources as well as deforestation (tropical forests) and erosion of humus associated with improper land use were estimated. The calculations were performed for the period 1860 – 2060, based on the above mentioned baseline scenario of the anthropogenic activities.

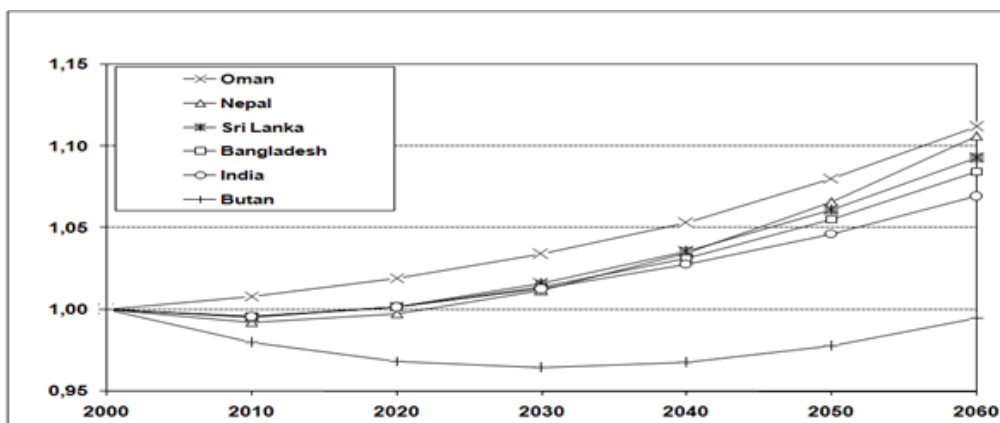
### 3. Results and discussion

In order to compare the changes in humus and phytomass, graphs were developed using relative values of variables by taking the year 2000 as a baseline year. Such a method of presenting the findings is convenient for comparative growth of the variables for one graph as well as for comparison of different variables in different countries, geographic zones and climatic zones. Figure 1 depicts the change in the amount of carbon in the phytomass in countries of South Asia during 2000-2060. It can be observed that there is an increase in the carbon emitted from phytomass in all countries of the study region in 2060, with the exception of Bhutan (Figure1). The largest increase in carbon content in the phytomass is observed in Pakistan, which reaches 11.06% in 2060, while the lowest is in Bangladesh - 10.7%.



**Figure 1.** Change in the amount of carbon in the phytomass in South Asia during 2000-2060.

Figure 2 shows the changes in humus carbon by 2060, of the countries in the study area. It can be noticed that the highest increase is in Pakistan (10.6%) followed by Nepal (10.4%), Sri Lanka (10.3 per cent) and finally in Bangladesh (10.1%). In this case, soil erosion is opposed to the growth of humus, associated with an increase in productivity and phytomass. There is impact compensation. Furthermore, the regional climate change affects the increase of humus. In India and Bhutan by the year 2060, the amount of carbon in the humus will be decreased as compared to its value in the year 2000, which means that the biosphere function of the regulation of the carbon cycle will be significantly weakened by the anthropogenic factor. Besides, in these countries the reduction in ecosystem productivity that is associated with the abrupt in climate change will have effect on the emitted carbon.



**Figure 2.** Change in the amount of carbon in the humus in South Asia during 2000-2060.

**Table 3.** The increase of carbon in phytomass, humus and content of total carbon in the plant formations of South Asia by 2060.

Region	Phytomass	Humus	Phytomass +Humus
Bangladesh	10,70	10,12	10,55
Bhutan	-	-	-
India	10,93	-	10,48
Nepal	10,46	10,45	11,12
Pakistan	<b>11,06</b>	<b>10,61</b>	<b>11,06</b>
Sri Lanka	10,85	10,31	10,66

Calculations of the absorption of carbon dioxide by ecosystems of South Asian countries were made by various researchers [5; 6; 7; 8; 15; 16; 17; 18; 19]. Using various mathematical models, such as HyLand, Lund-Potsdam-Jena DGVM (LPJ), ORCHIDEE, Sheffield-DGVM, TRIFFID, LPJ GUESS, NCAR CLM4C, NCAR CLM4CN, OCN, VEGAS, an increase of phytomass in South Asia was marked [18]. Also, Forest Survey of India (FSI) noted an increase of 5% of the forest area of India over the last 10 years, which is confirmed by the values predicted by the model. Along with mathematical models, remote sensing data were used, which allowed to assess long-term changes in carbon stocks in forest formations. The research demonstrating the growth of phytomass was carried out with the use of remote sensing data processed by the database GLOBALVIEW-CO2 on the mathematical model [19]. The use of the nine dynamic global models (DGVMs: CLM4.5, ISAM, 3, JULES, LPJ, LPJ\_GUESS, LPX, ORCHIDEE, VEGAS, VISIT) allowed us to obtain data about the increase of the ecosystem production of photosynthesis (NEP-Net Ecosystem Production) of South Asia [20]. In Bhutan, this increase was not recorded, due to the lack of growth of phytomass and humus, shown by the present study as predicted by the model.

The results of these studies confirm the findings of the current study using model calculations of the accumulation of carbon in the phytomass and humus ecosystems of South Asian countries for the period 2000-2060. The calculations show that the ecosystems of South Asian countries will be able to adapt to warming; an increase of greenhouse gas emissions may be short-term reaction, which with the development of more powerful vegetation and biomass growth will be replaced by carbon absorption.

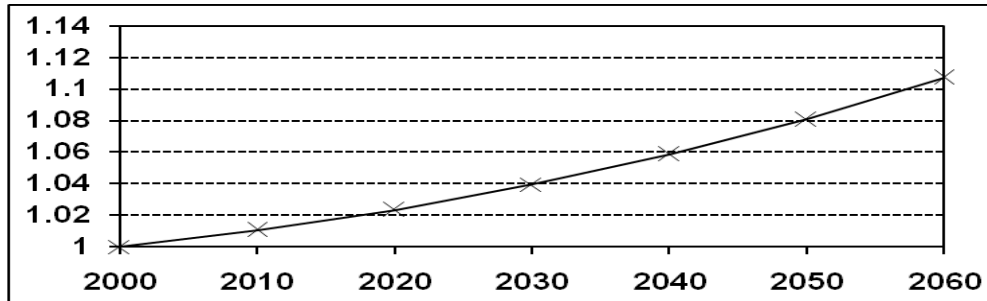
### *3.1. Comparison of regulatory functions of various types of plant communities of countries on the example of India.*

The capacity of ecosystems to use available climatic resources efficiently may serve as an important indicator for assessment of changes in the regulatory functions of ecosystems [9]. Total temperature use efficiency index (the amount of photosynthetic production per degree of annual temperature) most strongly decreased in the boreal zone, which suggests that the northern ecosystems are unable to adapt to the rapid growth of temperatures (their products are not growing or growing relatively slowly). Precipitation use efficiency index (the amount of production per unit of precipitation) decreased on large areas in tropical and boreal zone. Existing models have resulted in different predicted values of carbon amounts [5; 6; 7; 8; 15; 16; 17; 18; 19]. However, it can be assumed that according to the average assessment by the end of the century, the terrestrial ecosystems will act as a weak sink of carbon, but the relative value of this function will decrease along with the accumulation of CO<sub>2</sub> in the atmosphere [18]. The carbon stocks in the terrestrial biosphere will increase but the ability to absorb carbon from the atmosphere will strongly decrease [20]. Moreover, the largest growth of carbon stocks is projected in northern regions with sufficient moisture, and its greatest losses can be expected in regions where warming is accompanied by drying up of the climate [16; 20].

For comparative assessment of the regulatory functions of ecosystems based on the RAS CC spatial model of global carbon cycle, the present study investigated the carbon balance in the phytomass and humus of different types of plant communities in India for the period 2000-2060.

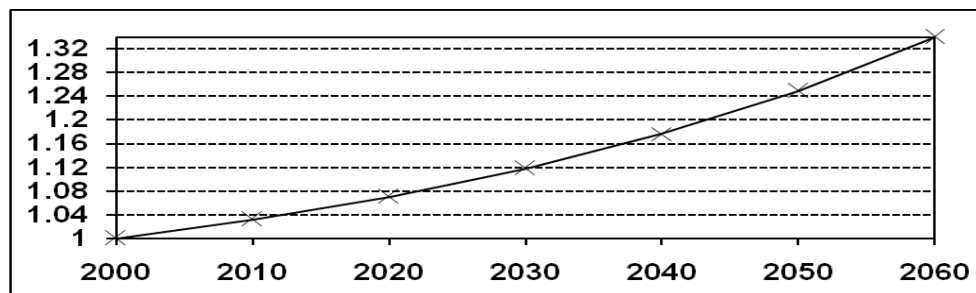
Mountainous tropical forests are a transitional zone between the mountainous forests of a moderate climate and truly tropical vegetation. In South India these forests grow at an altitude of about 1,070 m

above sea level; in the Central district and in Assam they are the dominant plant formation. Figure 3 shows that by 2060, the carbon gains will be 11.1%.



**Figure 3.** Tropical mountain forests. The total amount of carbon in phytomass and humus of plants per unit area ( $\text{t/km}^2$ ) during 2000-2060.

The Alps moderate forests grow at an altitude of 1.8 - 2.7 km above sea level. This forest belt is characterized by forests of coniferous breeds: Himalayan cedar (*Cedrus deodara*) and blue pine (*Pinus Wallichiana*). They grow mainly on the drier ranges of the Western Himalayas, where winter snowfall is common. According to the model calculations (Figure 4) in the cold coniferous forests by 2060, carbon gains will amount to 13.4%.



**Figure 4.** Cold coniferous forests. The total amount of carbon in phytomass and humus of plants per unit area ( $\text{t/km}^2$ ) during 2000-2060.

Indian tropical moist evergreen forests are characterized by average annual rainfall of 2,500 mm. These forests are on the Western Ghats, in the district of state of Assam and the Andaman Islands. In India gilei are multilayered and thick; there is vast species diversity. Here grow dipterocarpus (*Dipterocarpus pilosus*, *D. grandiflorus*, *D. griffithii*, *D. turbinatus*, *D. kerrii*, *D. incana*), Vateria Indian (*Vateria indica*), Artocarpus (*Artocarpus chaplasha*, *A. hirsita*, *A. heterophyllum*), terminalis (*Terminalia manil*, *T. bialata*, *T. procera*), Ceylon ironwood (*Mesua ferrea*) and many other representatives of tropical vegetation. According to the calculations carbon balance decreases sharply by 2020, then by 2060, it increases by 10.43%. Some species of tropical moist deciduous forests have a high economic value. These are teak (growing in the Central and southern parts of India), shala tree (growing in the States of Orissa. Bihar, West Bengal and Assam), various species of terminali (*Terminalia manil*, *T. bialata*, *T. procera*), *Pterocarpus dalbergioides* (near Andaman Islands) and *Pterocarpus marsupius*, *Dalbergia latifolia*, *Canarium euphyllum*, *Pterocymbium tinctorium* and *Bombax insignis*. Trees specific to this type of plant communities are characterized by the uniformity in height, which can reach 30 - 37 m. Basically there are deciduous trees, but there are also evergreen. The total content of carbon in phytomass and carbon in tropical seasonal forests will increase by 10.6% by 2060. Tropical dry deciduous forests grow along major Indian rivers – the Indus, Ganges, Brahmaputra, and others. In this type of forest communities there are shala and teak trees and mixed stands with different types of sandalwood (*Santalum album*) and other species (*Pterocarpus*

*santalinus*, *Boswellia serrate*, *Butea monosperma*, *Shorea talura*, *Terminalia tomentosa*, *Acacia catechii* etc.). The second tier is represented by bamboo (*Dendrocalamus strictus*). The problem of dry deciduous tropical forests is that of all other types of plant communities in India they are experiencing negative human impact. Large areas of forests along the rivers were destroyed with the aim of growing crops in their place. Tropical dry evergreen forests are on the east coast and stretch from the city of Tirunelveli (Tamil Nadu) to Nellore (Andhra Pradesh). This type of plant communities is the most common on the Indian plains, which are characterized by soil salinity and susceptibility to wind erosion. These are low-growing trees with leathery evergreen foliage. The trees are short and squat with a broad crown. Khirni (*Manilkara hexandra*) and black ebony (*Diospyros ebenum* *Eugenia*) are the main vegetation types in the dry evergreen forests of India. The undergrowth is presented with thorny bushes, intertwined with lianas, which make the forest impenetrable. By 2060, the increase in carbon content of tropical dry forests is estimated to account for 11.8% compared to 2000.

It should be noted that the amount of carbon of the phytomass and humus of all types of ecosystems in India is going to increase by 2060, due to the growth of CO<sub>2</sub> concentration in the atmosphere and temperature rise caused by global warming. Table 4 shows the summarized modeling results of the total carbon change in different types of plant communities in the countries of India.

According to the model calculations, the maximum increase of the total carbon is observed in cold coniferous forests and is 13.4%. Studies of foreign authors [21-22] confirm the high depositing ability of the forests of the Himalayas: the maximum carbon stock was recorded in the forests of Arunachal Pradesh and equals 11.27% of the total in India. It should be noted that the Northeastern Himalayan subalpine conifer forests occupy the area of 46,300 km<sup>2</sup> in the Eastern part of the Himalayas, at an altitude of 2,500 – 4,200 m above sea level, which greatly impedes their economic use. A minimal increase, amounting to 10.43%, is observed in tropical evergreen forests and can be explained by a sharp decrease in the carbon balance by 2020, due to deforestation and soil erosion associated with poor land use. The reduced capacity for carbon sequestration can be explained not only by anthropogenic but also natural reasons: landslides and bamboo flowering. Variability of carbon sequestration by different types of vegetation communities is primarily due to degradation of vegetation and not the actual features types. This is caused by spatial and temporal changes in the structure, density (closeness of the dome, the density of trees) and species composition.

**Table 4.** The increase in total carbon of phytomass and humus of various types of plant communities in India by 2060.

Type of plant community	The increase in the total number of carbon (%)
tropical mountain forests	11,1
cold coniferous forests	13,4
tropical evergreen forests	10,43
tropical seasonal forest	10,6
tropical dry forests	11,8

It should be noted that National Action Plan on Climate Change (NAPCC) adopted by the National Mission for Green India (GIM), in the framework of which there is an increase in forest cover by 5 million hectares (especially the rocks with the maximum repository capacity) with the aim of improving ecosystem functions (capture and storage) of carbon. Agroforestry systems can have an indirect effect on carbon sequestration as it helps to reduce the pressure on natural forests, which are the largest sinks of terrestrial carbon. The impact of agroforestry on soil carbon flow increases the speed by 2-3 t/ha per year.

The amount of carbon of the phytomass and humus of all types of ecosystems in India is going to increase by 2060, due to the effect of increasing the concentration of CO<sub>2</sub> in the atmosphere and temperature under global warming. This phenomenon can be explained by the regulatory action of carbon dioxide on the growth function of plants. Such a function is enhanced by the formation of new



photosynthetic apparatus. This indicates a dual role of CO<sub>2</sub> as a substrate in photosynthesis and as a regulator of growth processes. For tropical seasonal forests and tropical evergreen forests we can see a reduction in the amount of carbon in the phytomass and humus by 2020 and 2030, respectively. In this case, these plant formations are a net source of carbon for the atmosphere. The release of CO<sub>2</sub> during the oxidation of biomass is not the only source of carbon while cutting down tropical forests. Transformation of forest land to agricultural area, when plowing oxidizes a considerable part of organic matter can also lead to the inflow of carbon into the atmosphere.

The modeling results indicate the accumulation of carbon in the phytomass and humus of the ecosystems of South Asian countries for the period 2000-2060. By 2060, the total amount of carbon in tropical dry evergreen and seasonal forests is going to increase, which is associated with a high degree of absorption of CO<sub>2</sub> in the tropics, while bringing about proper measures for national forest policy.

The calculations can be used to define the biosphere resilience of the countries to human impact in terms of increasing carbon dioxide concentration and to study the dynamics of forest degradation from anthropogenic and climatic influences. The results of the forecast can be used as a decision making tool in planning environmental practices within the study area.

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### Acknowledgments

This research was financially supported by the Ministry of Education and Science of the Russian Federation (The Agreement number 02.a03.0008)