

# **Modeling and Assessment of Carbon Dioxide Concentration Emitted from the Coal-based Power Plant in Bangladesh**

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## **Abstract**

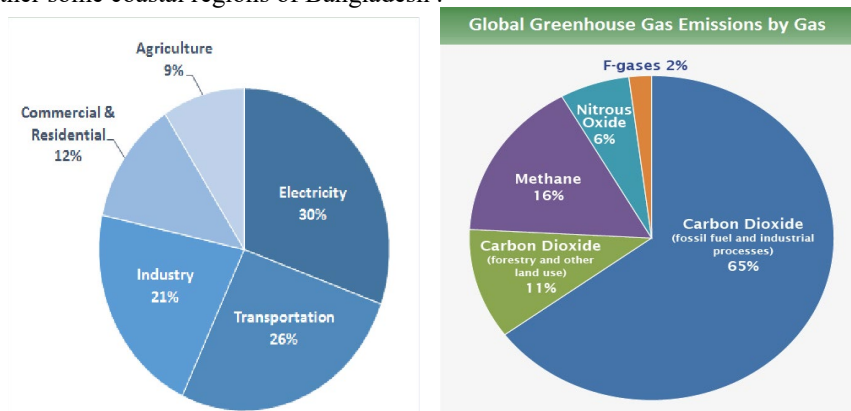
A coal based power plant is considered as one of the main sources of the emission of carbon dioxide, which is the principal etiological agent for climate change due to global warming, and thus poses great threat to the Sundarbans, the largest mangrove forest in the world and its surrounding regions because of a high emission rate of greenhouse gases (GHGs) such as carbon dioxide. In this paper, we propose a nonlinear mathematical model to assess the emission of carbon dioxide, produced from the coal-based power plant at Rampal in the Bagerhat district of Bangladesh and its possible aftermath on the ecosystem. We study the process using a three compartmental ecological model which is generally used for modeling dynamic ecosystems and process to assess the concentration of greenhouse gases like CO<sub>2</sub>. The model has been analyzed both analytically and numerically. The analytical findings have been validated with the numerical simulations.

**Keywords:** Coal-based fuel, Carbon dioxide, Climate change, Mathematical model, Numerical simulation.

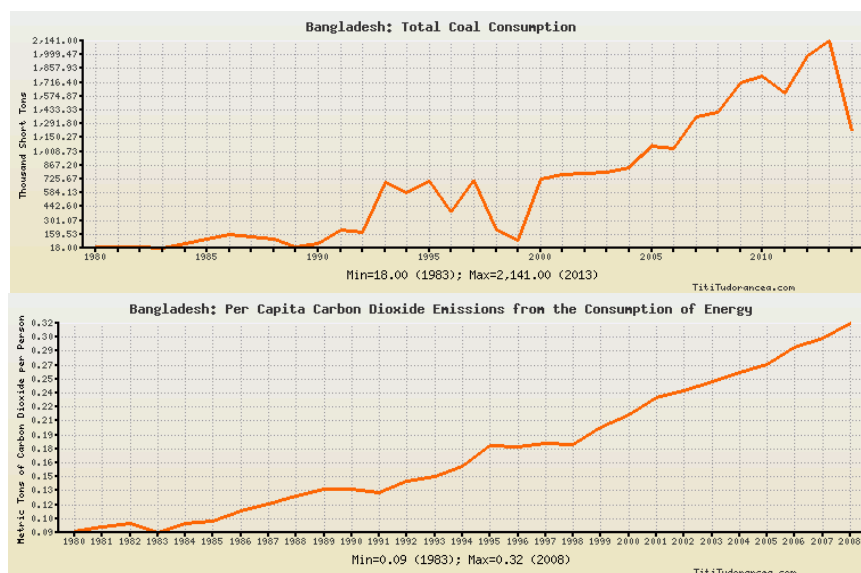
## **1. Introduction**

Coal based power plant produces electricity by burning coal in a boiler to heat water to produce steam. The steam, at tremendous pressure, flows into a turbine which spins a generator to produce electricity. The steam is cooled, condensed back into water, and returned to the boiler to start the process over. Burning coal is a leading cause of smog, acid rain, global warming, and air toxics. In an average year, a typical coal plant generates: i) ( 3,700,000 tons of carbon dioxide )CO<sub>2</sub>(, the primary human cause of global warming--as much carbon dioxide as cutting down 161 million trees; ii) ( 10,000 tons of sulfur dioxide )SO<sub>2</sub>( which causes acid rain that damages forests, lakes, and buildings, and forms small airborne particles that can penetrate deep into lungs; iii) ( 500 tons of small airborne particles, which can cause chronic bronchitis, aggravated asthma, and premature death, as well as haze obstructing visibility; iv) ( 10,200 tons of nitrogen oxide )NO(, as much as would be emitted by half a million late-model cars. NO leads to formation of ozone )smog( which inflames the lungs, burning through lung tissue making people more susceptible to respiratory illness; v) ( 720 tons of carbon monoxide )CO(, which causes headaches and place additional stress on people with heart disease; vi) ( 220 tons of hydrocarbons, volatile organic compounds )VOC(, which form ozone; vii) ( 170 pounds of mercury, where just 1/70th of a teaspoon deposited on a 25-acre lake can make the fish unsafe to eat; viii) ( 225 pounds of arsenic, which will cause cancer in one out of 100 people who drink water containing 50 parts per billion and ix) ( 114 pounds of lead, 4 pounds of cadmium, other toxic heavy metals, and trace amounts of uranium.) Chowdhury 2017(. Coal plants are one of the top sources of carbon dioxide )CO<sub>2</sub>( emissions and the primary cause of global warming. Coal burning is one of the main causes of creating smog, acid rain, and toxic air pollution. Despite of these facts, the Bangladesh government planned for a 1320 megawatt coal-based power station at Rampal in Bagerhat district of Bangladesh. This work is proposed as a joint partnership between India's state-owned National Thermal Power Corporation and Bangladesh Power Development Board. The joint venture company is known as Bangladesh India Friendship Power Company )BIFPC(. The proposed project, on an area of over 1834 acres of land, is situated 14 kilometers north from the edge of the world's largest mangrove forest Sundarbans which is a UNESCO world heritage site. Coal fired Rampal power plant planning is considered to be one of the most controversial decisions as this project has environmental issues. The crucial discussion about environmental security of Sundarbans is not satisfied yet. Regarding this we tried to find out the natural capability of Sundarbans to face environmental changes which will be implied by this plant. We tried to figure out the

approximate carbon emission by that power plant and calculated the tolerance level of Sundarbans by itself. Beside this we discuss about technologies which may actually secure Sundarbans from being destroyed. )Mazumder *et al.* 2016(. Now, we can see from Figures 1 and 2, the real causes why this power plant can be a great threat to Sundarbans and other some coastal regions of Bangladesh .



**Figure 1:** Total greenhouse gases emission from different sectors.

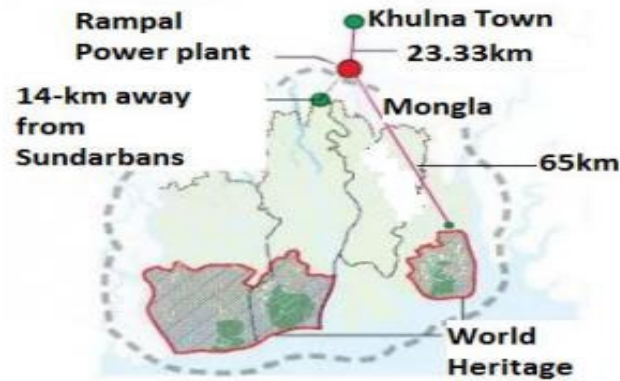


**Figure 2:** Total coal consumptions (upper one) and per capita carbon dioxide emission from the consumptions of energy (lower one).

**Table 1:** Installations of power plant in MW in Bangladesh

Type of Power Plant	2011	2012	2013	2014	2015	2016
Gas	544	460	1,114	1,408	450	1,500
Coal				550	1,900	1,300
FO <sup>1</sup>	1,248	1,145				
Diesel	100					
Gas/FO	302	390	520	365		
Gas/Diesel/HSD <sup>2</sup>		150	0			
Wind			100			
Solar		12				

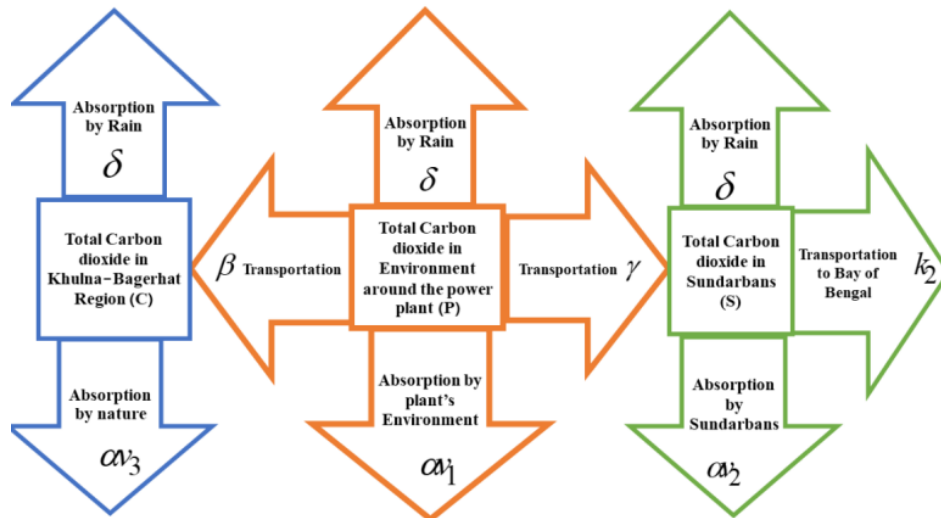
From Table 1, we can observe that, the electricity sector produces most of the greenhouse gas over the world. In Bangladesh, the number of coal and gas based power plants have increased heavily from 2014. So, It's very concerning and a threat to our environment. From Figure 3, we can see the distances of different surrounding regions from the power plant, which are considered to be affected by the greenhouse gases of emitted from the power plant.



**Figure 3:** Location of the Coal-based Power Plant from the Largest Mangrove Forest Sundarbans and Khulna-Bagerhat Region.

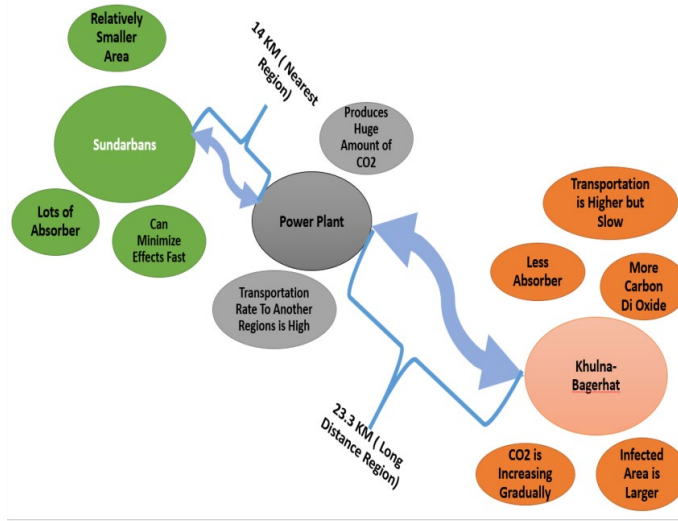
## 2. Basic Assumptions and Mathematical Formulation

We assume that the total carbon dioxide emitted from the power plant are distributed into several ways. As the environment around the plant is considered as the first initial compartment for storing the carbon dioxide, we can define the distribution of the emission, concentration and absorption of carbon dioxide as shown in **Figure 4**.



**Figure 4:** Schematic distribution diagram of the emission, concentration and absorption of carbon dioxide from power plant to another two region.

We described the assumptions by using **Figure 5**.



**Figure 5:** All necessary assumptions considered for the proposed three compartmental model

## 2.1 Model Formulation

Mathematical models play important roles in describing and assessing the complex behaviors and insights of dynamical systems and we refer readers to (Biswas *et al.* 2016, 2017; Islam *et al.* 2017; Mallick and Biswas 2017, 2018; Mondal *et al.* 2016; Mondol *et al.* 2018) for some recent developments on modeling in diverse applications. From these motivational works, we now formulate our proposed model. Considering the assumptions described in Figure 5, and taking the diagram in Figure 4 into account, we can describe this process by a three-compartmental mathematical model in terms of a system of nonlinear ordinary differential equations as follow:

$$\frac{dP}{dt} = a - \delta P - \alpha v_1 P - \beta P - \gamma P \quad (1)$$

$$\frac{dS}{dt} = \gamma P - \frac{\alpha v_2 S}{P\rho} - k_2 S - \delta S \quad (2)$$

$$\frac{dC}{dt} = \beta P - \frac{\alpha v_3 C}{P\phi} - \delta C \quad (3)$$

with the initial conditions

$$P(0) = P_0 \geq 0; S(0) = S_0 \geq 0; C(0) = C_0 \geq 0. \quad (4)$$

The variables and parameters used in the model (1)-(4) are summarized in Table 2.

**Table 1** Description of symbols and parameters used in this model

Symbols	Descriptions
$P(t)$	Amount of Carbon dioxide at power plant area
$S(t)$	Carbon dioxide in plant's environment including Sundarbans
$C(t)$	Carbon dioxide in Khulna Bagerhat region
$\gamma$	Rate of carbon dioxide emission from plant's environment to Sundarbans
$\beta$	Rate of carbon dioxide transportation to Khulna – Bagerhat region
$v_1, v_2, v_3$	Total Carbon Dioxide absorber trees area at each region.
$k_2$	Rate of carbon dioxide transportation to Bay of Bengal
$\alpha$	Rate of carbon dioxide absorption trees
$a$	Total amount of Carbon dioxide storing at a constant amount from the power plant

$\delta$	Rate of carbon dioxide absorption by Rain water
$\rho$	Rate of excess or less carbon dioxide transportation by air to Sundarbans due to production
$\phi$	Rate of excess or less carbon dioxide transportation by air to Khulna– Bagerhat region due to production

### 3. Model Analysis

The model has been analyzed in order to describe the dynamics of concentration and absorption. The objective of this analysis is to find and verify the amount of carbon dioxide produced from Rampal power plant, for that a closed set has been considered as

$$\Omega = \{(P(t), S(t), C(t)) \in \mathbf{R}_+^3\} \text{ with the initial conditions } P(0) \geq 0, S(0) \geq 0, C(0) \geq 0.$$

#### 3.1 Analytical Analysis

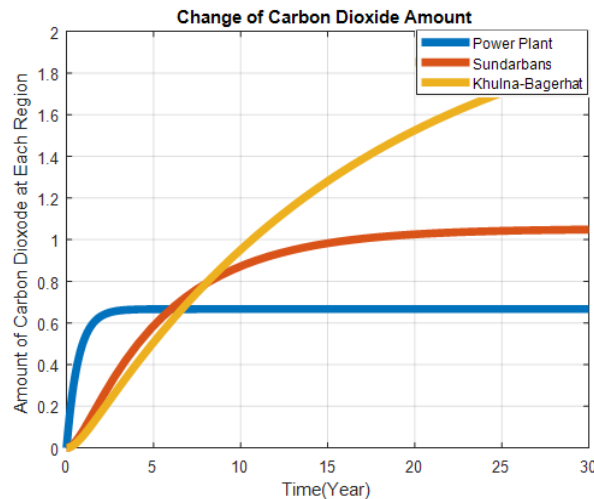
Now through the positivity of solutions of the model in the Theorem 3.1, it is easy to prove that all the variables in the model of system of equations are positive (see also Sahani et al., 2017; Sardar et al., 2018).

**Theorem 3.1:** If,  $P(0) \geq 0, S(0) \geq 0, C(0) \geq 0$ , then the solutions  $P(t), S(t)$  and  $C(t)$  of the model (1)-(4) presented by the system of equations are positive.

Let us take the equilibrium point as  $E^*(P^*, S^*, C^*)$ , then solving the model (1)-(4) for the equilibrium point as

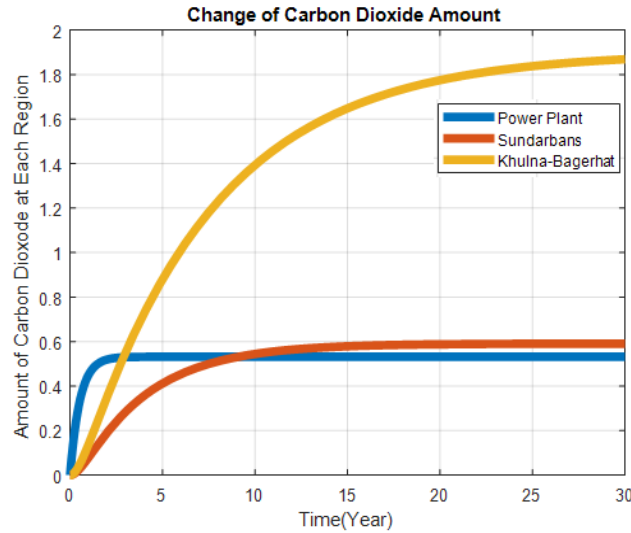
$$E^* = \left( \frac{a}{\beta + \delta + \gamma + \alpha \eta}, \frac{a^2 \gamma \rho}{(\beta + \delta + \gamma + \alpha \eta)(\alpha^2 \eta \nu_2 + a \delta \rho + \alpha \beta \nu_2 + \alpha \delta \nu_2 + a k_2 \rho + \alpha \gamma \nu_2)}, \frac{a^2 \beta \phi}{\nu_3 \alpha^3 \eta^2 + 2 \nu_3 \alpha (\delta \gamma + \alpha \delta \eta + \alpha \gamma \eta + \beta \delta + \beta \gamma) + I} \right) \quad (5)$$

Now, we plot the analytical solution of the model for 30 years of time period under various conditions. At first, we consider that maximum amount of carbon dioxide is transported to Khulna-Bagerhat region and by taking the initial amount of carbon dioxide of three regions 0, 0 and 0 respectively. Assuming 30% of total carbon dioxide transported to Khulna Bagerhat region and 40% to Sundarbans where Sundarbans can absorb 80% of transported carbon dioxide and Khulna Bagerhat region can absorb 20% of total transported carbon dioxide by trees. These scenarios are shown in **Figures 6 and 7**.



**Figure 6:** Analytical solution of the model where 70% of total carbon dioxide is transported to another two regions.

If the carbon dioxide produced from the power plant is transported to Khulna-Bagerhat region at a higher rate than Sundarbans then assuming all of our basic assumptions true with initial conditions  $(0,0,0)$  (the carbon dioxide level of 3 regions over 30 years is shown in **Figure 7**).

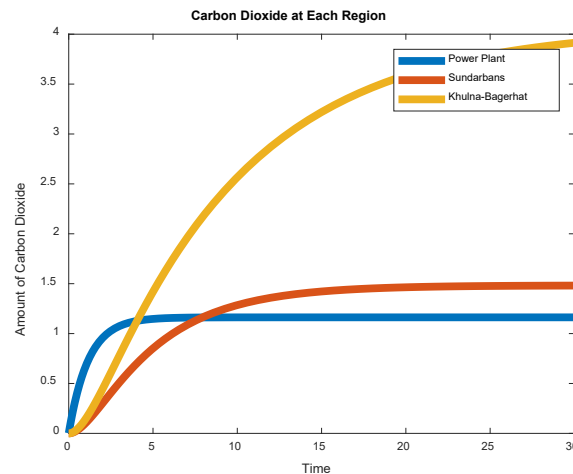


**Figure 7:** The graph shows the analytical solution of the model where 50% of carbon Dioxide is transported to Khulna-Bagerhat region.

Also, testing the stability of the model at the equilibrium point  $E^*(P^*, S^*, C^*)$ , it can be concluded that the proposed model is asymptotically stable.

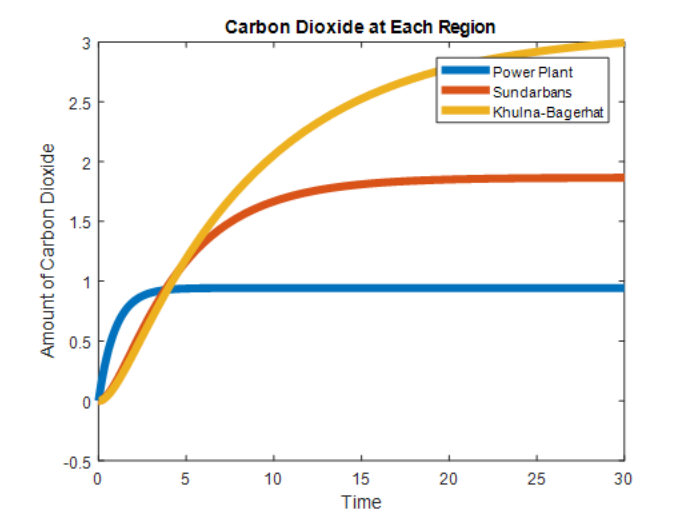
### 3.2 Numerical Analysis

We now solve the model numerically based on the respective parameters present in the system of equations (4.1). The simulations are carried out using MATLAB programming language by the set of parameter values and initial conditions. The purpose of this simulation is to investigate the behaviors of our model and describe the dynamics of carbon dioxide concentration, Transportation and Absorption. Assuming 40% of total carbon dioxide transported to Khulna Bagerhat region and 50% to Sundarbans where Sundarbans can absorb 30% of transported carbon dioxide and Khulna Bagerhat region can absorb 40% of total transported carbon dioxide.



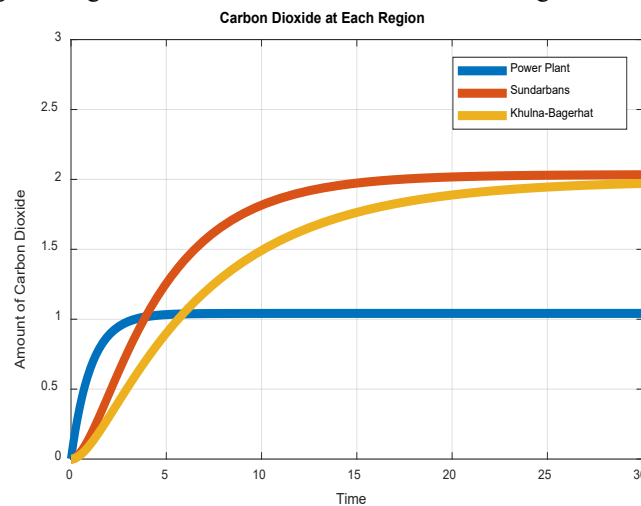
**Figure 8:** The graph represents the numerical solution of the model where 50% of the total carbon dioxide is transported to Khulna-Bagerhat region.

Assuming 40% of total carbon dioxide transported to Khulna Bagerhat region and 30% to Sundarbans where Sundarbans can absorb 70% of transported carbon dioxide and Khulna Bagerhat region can absorb 50% of total transported carbon dioxide.



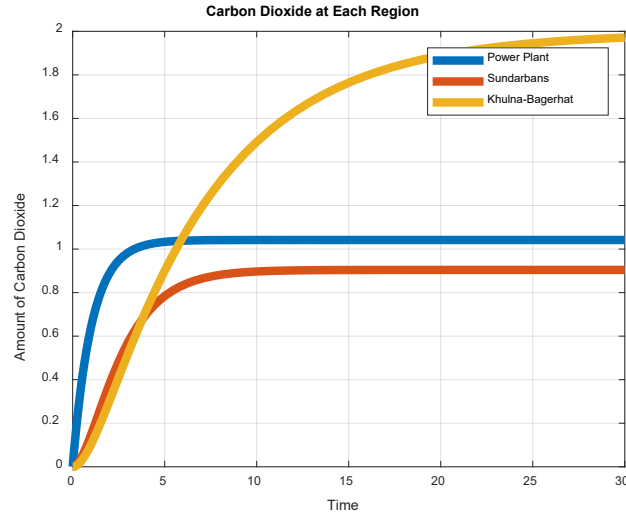
**Figure 9:** Numerical solution of model where total 30% of carbon dioxide is transported to Khulna-Bagerhat region and 40% to Sundarbans.

Assuming there exists more trees at Khulna-Bagerhat region, where the total area of trees of Sundarbans is assumed as 60% and of Khulna-Bagerhat region as 40% , this scenario is shown in Figure 10.



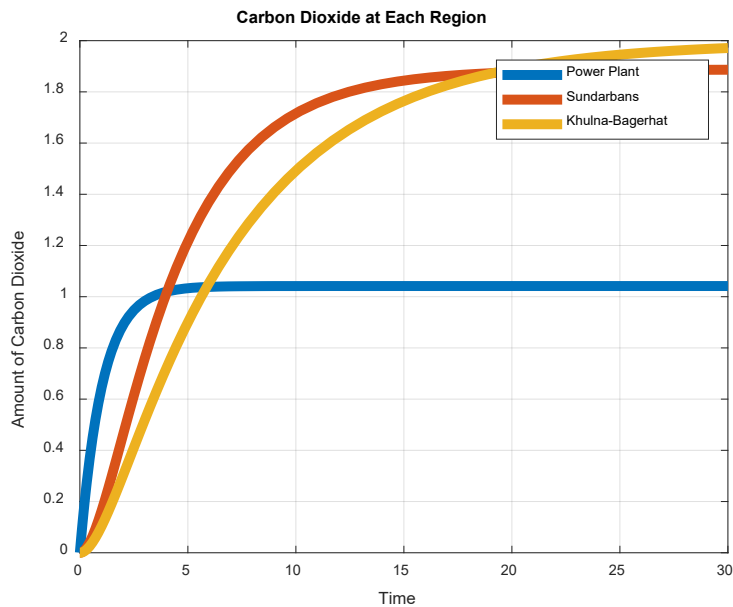
**Figure 10:** Numerical solution of the model showing that Sundarbans have 60% absorption of carbon dioxide and Khulna-Bagerhat region has 40%.

If about 40% of total carbon dioxide of Sundarbans transported from power plant's region is transported to the Bay of Bengal, that scenario is shown in Figure 11.



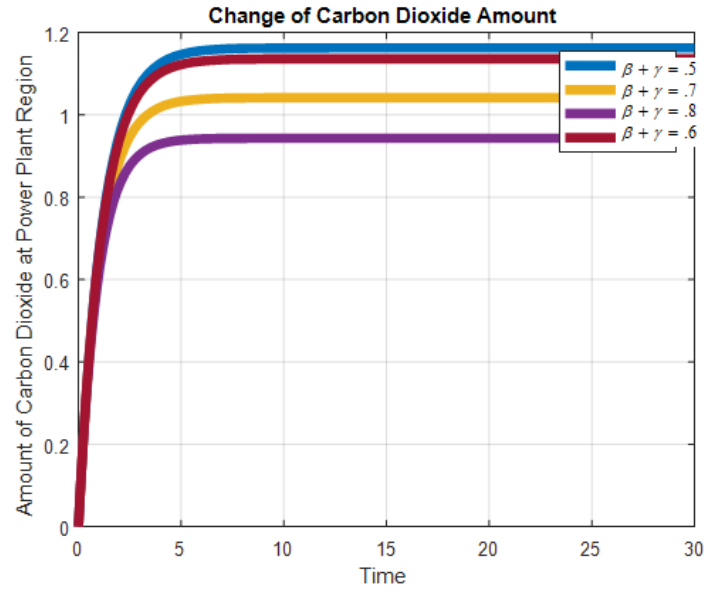
**Figure 11:** Numerical solution of the model shows that total 40% of carbon dioxide of Sundarbans is transported to Bay of Bengal and 50% is transported to Sundarbans initially.

If at least 10% of total carbon dioxide of Sundarbans transported from power plant's region is transported to the Bay of Bengal then this simulation result is shown in Figure 12.



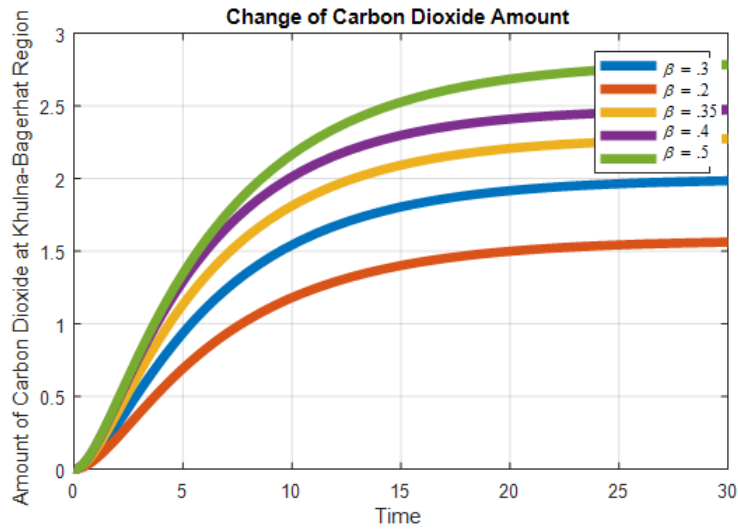
**Figure 12:** Numerical solution of the model where total 10% of carbon dioxide is transported to Khulna-Bagerhat region and 50% is transported to Sundarbans initially.

The amount of carbon dioxide at each region for different values of parameters keeping other parameter values same as before is shown in Figure 13.



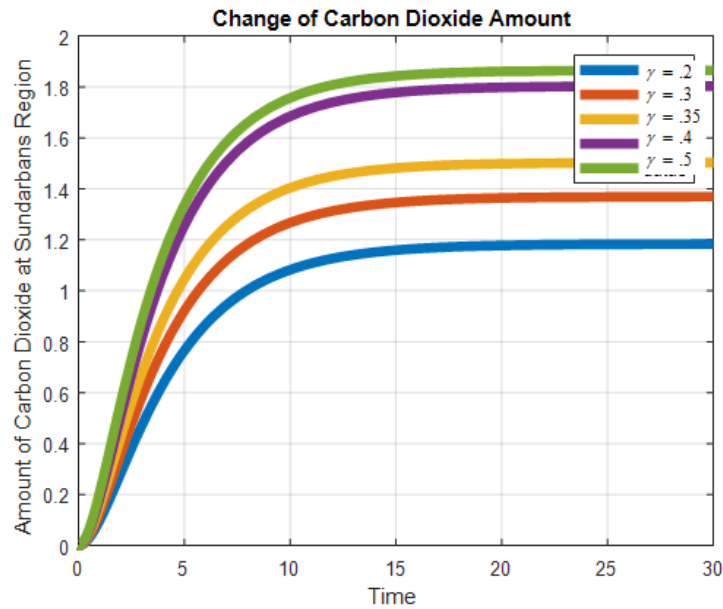
**Figure 13:** This graph shows the total amount of carbon dioxide at the surroundings of power plant for various rate of transportation.

The amount of carbon dioxide at Khulna-Bagerhat region for different values of beta keeping other parameter values same as before is shown in Figure 14.



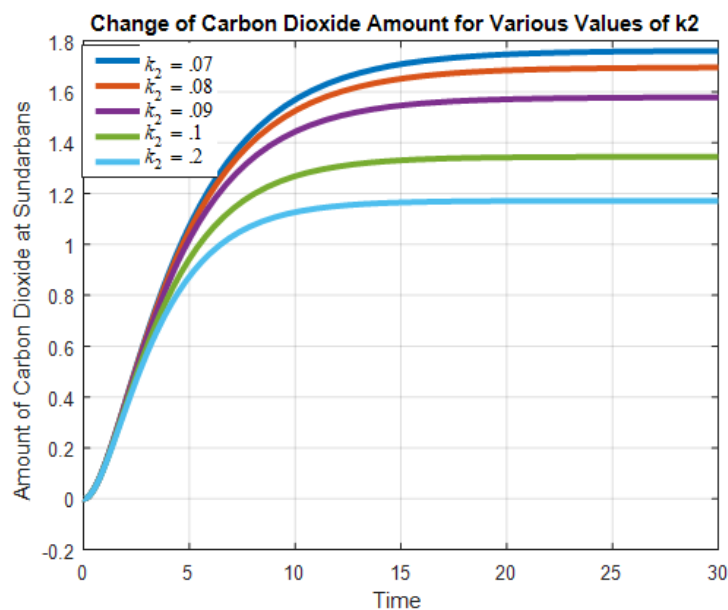
**Figure 14:** Amount of carbon dioxide at Khulna-Bagerhat region for various rate of transportation from power plant's surroundings.

The amount of carbon dioxide at Khulna-Bagerhat region for different values of gamma keeping other parameter values same as before is shown in Figure 15.



**Figure 15:** Amount of carbon dioxide at Sundarbans region for various rate of transportation from Power Plant's Surroundings.

If the transportation of carbon dioxide towards the Bay of Bengal increases or decreases, then the amount of carbon dioxide at Sundarbans region is shown in Figure 16.



**Figure 16:** Carbon dioxide amount at Sundarbans region for various rate of transportation from Sundarbans to Bay of Bengal.

If the maximum amount of carbon dioxide is transported to the Bay of Bengal, the Sundarbans have to absorb a little amount which won't be harmful for Sundarbans. This will be possible if the pipes from which the Carbon Dioxide is emitted are high enough to fall on the ground during the time. Most of the Carbon Dioxide can pass a long distance towards the Bay of Bengal. The Carbon Dioxide level for various combinations of  $k_2$  and  $\gamma$  are shown in Figures 15 and 16.

## 4. Conclusions

From the above solutions, analysis, numerical simulations and figures, we can conclude that the amount of carbon dioxide will increase instantly at Sundarbans but Because of having higher carbon dioxide absorption capacity, Sundarbans will absorb almost all the Carbon Dioxide slowly and there will exist only newly transported carbon dioxide at the environment of Sundarbans. Some carbon dioxide are transported to Bay of Bengal. If the rate of transportation to Bay of Bengal increases then Sundarbans have to absorb little amount of carbon dioxide and the level of carbon dioxide will be almost same here. But the carbon dioxide absorption capacity of Khulna-Bagerhat region is relatively very low than Sundarbans but carbon dioxide transportation takes some time here. Because of this, the amount of carbon dioxide will increase slowly if less carbon dioxide will enter here. Otherwise it will increase highly and become stable after a certain time period. At power plant's environment, carbon dioxide will increase highly but get transported to various directions through air. Since transportation is a very slow process, there exist a big amount of carbon dioxide always around the power plant.

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