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# Assessment of GHG Emissions from Sardar-Sarovar Reservoir in India using GHG Risk Assessment Tool

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***Abstract:***
Climate change and the occurrence of extreme weather conditions are the major concepts which are linked to global warming. The hydropower has been considered as clean source of energy by recent studies has proven that the creation of a dam along a water body will result in the greenhouse gases (GHGs) emission which is answerable for global warming. The OM originates from the flooded area, acts as the primary production in the reservoir which flows from upstream to downstream part of the reservoir. The multiple pathways in which the gases reach the atmosphere are in diffusing flux, bubbling, flux through macrophytes and in the upstream and downstream of the reservoir itself. A large amount of gases is also released into the atmosphere when the water is passing the turbine and the spillway. When globally compared some reservoirs, emission are very high when compared with thermo-power plants. In this paper past 16 years data of seven hydro power stations which are in India at different climatic zones has been analyzed. A mean annual daily temp from past 16years (1997-2012) has been analyzed for seven hydro power stations in India Similarly for rainfall, mean annual rainfall over 16 years being obtained. And finally, by using UNESCO/IHA GHG Risk Assessment Tool (Beta Version) speculated diffusive fluxes in $CO_2$eq has been calculated for that particular year and predicted values over hundred years for the selected hydro power stations are also obtained using the same tool.

***Keywords:*** *Active and passive Controls, Viscous dissipation, Chemical reaction, Magnetohydrodynamic, variable conductivity, Thermal radiation.*

## I. Introduction

In this a model has been designed and used for estimating the minimum and maximum limits of GHG emissions from a reservoir by studying the various components/ parts of the water reservoir in a hydro power scheme. The multiple pathways in which the gases reach the atmosphere are by diffusing flux, bubbling, flux through macrophytes and in the river downstream of reservoir itself. A large amount of gases is also released into the atmosphere when the water is passing through the turbine and the spillway. The organic matter(OM) which is present in terrestrial ecosystem (biosphere and lithosphere) will get transported to water bodies like rivers, lakes and water flow by surface and sub-surface flow. The OM originated from the flooded area, acts as the primary production in the reservoir which flows from upstream to downstream part of the reservoir. Further, storage-based hydropower projects which are located in the tropics represent an important anthropogenic GHGs source. This paper describes the model used for estimating the GHGs emission from a reservoir as suggested by UNESCO/IHA GHG Research Project (2009). This model uses the secondary data available in literature for estimating the ranges for GHGs emissions. The methodology has been explained with the help of a real time case study of a hydropower project from India.

## II. Pathways of GHG Emissions From Reservoir

Working creation of a reservoir, emission from different parts of the reservoir will takes place. As per water bodies emission the main GHGs which are

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calculated are $CO_2$ and $CH_4$. This both gases are released into atmosphere as diffusive flux, degassing and $CH_4$ is released in the form of bubbles from bottom sediment part of reservoir but at favorable conditions.

**Reckoning of Diffusive Flux from Aquatic Ecosystem**

**1. Diffusive Flux:**Toward Air-water interface this both CO2 and CH4 will be moved by dissemination from the amphibian biological systems. This pathway occurs at store upstream and downstream and it depends on the Henry's law contrast of fractional weight of a gas between the air (Pa) and the water (Pw). On the off chance that Pw is higher than Pa the gas diffuses from the water to the climate on the grounds that a synthetic compound consistently diffuses from the most thought layer to the less focused.

**2. C-$CO_2$ Flux model precepts:**Respective elective details were endeavored by the UNESCO/IHA ozone harming substance outflows from freshwater repositories research venture the accompanying general articulation has been given as the best fitting articulation which consider the parameters which are in charge of the discharge of CO2 from the repository by thinking about the period of store.

$$Flux\,C-CO_2 = 186.0 + 0.148\times R + \left(944.485 + 1.91\times T + 0.09727\times T^2\right) \times e^{-0.044\times\left[52.339-0.7033\times T-0.0358\times T^2\right]\times Age}$$

The above formula is the best framed after several attempts and the above depends on three main parameters they are 1) Runoff (R) 2) Temperature (T) 3) Age of the reservoir. Reasons for consideration of these parameters are:

- Ultimate CO2 discharge happens in the wake of flooding so certain factor of temperature
- The new long-haul harmony outflow (after the underlying heartbeat) is a positive factor of overflow. Higher the spillover higher the CO2 discharge from the supply
- The steepness of the underlying decrease (the exponential term) is a negative capacity of temperature

**Range of variability of the estimates**

The predicted value has been estimated by using the equations which have been explained in section 6.4.1. And the values of the "lower limit" and the "upper limit" can be estimated as an element of the anticipated estimations of gross GHG motions (of CH4 and CO2) and the mean square blunders. Table 1 communicates how to evaluate the estimations of the points of confinement of the 67% certainty interim.

**Table 1: Limits of predicted values of the 67% confidence interval**

| Predicted Value | Lower limit | Upper limits |
|---|---|---|
| Gross C-$CO_2$ Flux | $\frac{1}{2.3}$* "Predicted Gross C-$CO_2$ Flux" | 2.3* "Predicted Gross C-$CO_2$ Flux" |
| Gross C-$CH_4$ Flux | $\frac{1}{3.55}$* * "Predicted Gross C-$CH_4$ Flux" | 3.55* "Predicted Gross C-$CH_4$ Flux" |

*(Both models have uncertainty best described on a base-10 logarithmic scale. Consequently, the factors 2.3 and 3.55 are derived from $10^{0.36}$ and$10^{0.55}$, respectively.)*

The confidence interval for the predictions is obtained as:

$$P\,[\text{"lower limit"} \le \text{"GHG flux"} \le \text{"upper limit"}] = \alpha\%$$

Meaning that there is α% of probability that the "GHG flux" will be in the interval between the " lower limit" and the "upper limit". The values for "lower limit" and "upper limit" of the 67% confidence interval for the predictions are taken from table.

## III. CASE STUDY ON SARDAR-SAROVAR

The Sardar-Sarovar Hydro power has two power houses - River Bed Powerhouse and Canal Head Power House with combined installed capacity of 1450 MW and benefits to be shared between Madhya Pradesh, Maharashtra and Gujarat.A GIS switch yard complex, and the 400 KV power

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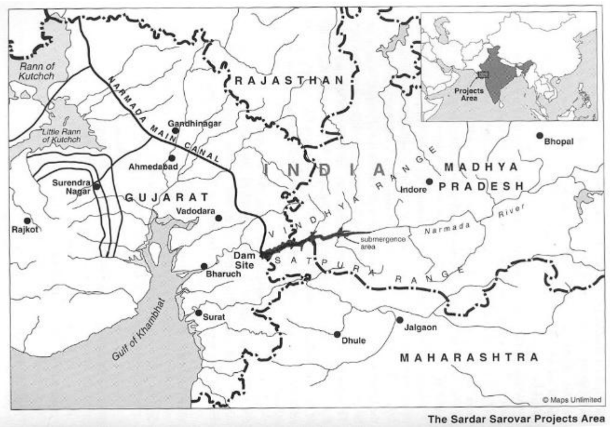
transmission network up to MP-Gujarat and Maharashtra -Gujarat borders in Gujarat and the project area is shown in the Figure 1.

Location coordinates of Sardar-Sarovar reservoir are: Latitude= 21.826, Longitude= 73.749.It is a reservoir formed by the main dam with a gross storage capacity of 0.95 million-hectare meters (7.70 MAF) and a live storage of 0.58 million hectare meters (4.73 MAF).



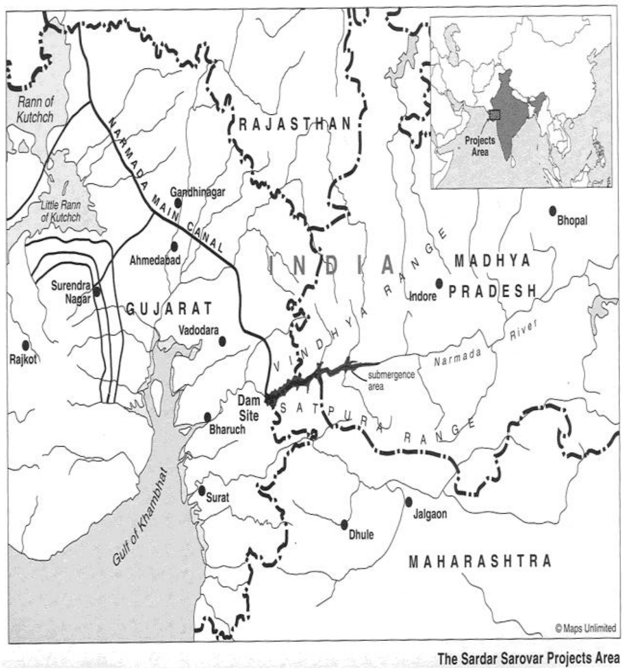




Fig. 1 Project area of Sardar – Sarovar

**Table 2 Details of Power Installation of Sardar-Sarovar**

| Sardar-Sarovar Reservoir | | | | | |
|---|---|---|---|---|---|
| **Station name** | **Type** | **Type of POWERHOUSE** | **units** | **Rated capacity of units** | **Installed capacity** |
| Sardar-Sarovar (CHPH) | Kaplan (Conventional) | Surface | 5 | 50 MW | 250MW |
| Sardar-Sarovar (RBPH) | Francis (Reversible) | Underground | 6 | 200 MW | 1200 MW |
| | | **Total** | **11** | | **1450MW** |

## IV. Estimation of Complete Emission from Sardar-Sarovar Reservoir

**Diffusive flux:** The data of the Sardar-Sarovar RBPH had been collected according to the latitude and longitude basics, the mean annual daily air temperature and Mean annual precipitation from the located surface has been broke down by gathering the information from 1997-2012 from NASA Prediction of Worldwide Energy Resource (POWER). Run-off information are gotten from UNH/GRDC composite run-off fields V 1.0. Also, the investigated qualities are appeared in the Table 2

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**Table 3: Details of Sardar-Sarovar RBPH for Diffusive Fluxes calculation using UNESCO/IHA Risk Assessment Tool**

| STATION | SA $Km^2$ | AGE | DMAP (1997-12) (mm/year) | RUN OFF (mm/year) | DMAT ($^0C$) (1997-12) | LAT | LON |
|---|---|---|---|---|---|---|---|
| Sardar Sarovar-RBPH | 375.33 | 8 | 960.14 | 408 | $27^0C$ | 21.82 | 73.98 |

*SA – Surface Area, DMAP- Daily Mean Annual Precipitation, R – Runoff, LAT- Latitude, Lon – Longitude, DMAT - Daily Mean Annual Temperature*

**Table 4Thresholds limits for CO2 and CH4 emissions (mg C-$CO_2$ $m^{-2}$ $d^{-1}$)**

| Thresholds for comparison with calibration dataset | | | | | | | |
|---|---|---|---|---|---|---|---|
| $CO_2$ (mg C-$CO_2$ $m^{-2}$ $d^{-1}$) | | | | $CH_4$ (mg C-$CH_4$ $m^{-2}$ $d^{-1}$) | | | |
| LOW | MEDIUM | | HIGH | LOW | MEDIUM | | HIGH |
| Smaller than | Between | | Bigger than | Smaller than | Between | | Bigger than |
| 109 | 109 | 628 | 628 | 3 | 3 | 45 | 45 |

**Table 5 Predicted values over hundred years**

| Time (year) | $CH_4$ (mg C-$CH_4$ $m^{-2}$ $d^{-1}$) | $CO_2$ (mg C-$CO_2$ $m^{-2}$ $d^{-1}$) | lower limit $CO_2$ (mg C-$CO_2$ $m^{-2}$ $d^{-1}$) | Upper limit $CO_2$ (mg C-$CO_2$ $m^{-2}$ $d^{-1}$) | lower limit $CH_4$ (mg C-$CH_4$ $m^{-2}$ $d^{-1}$) | Upper limit $CH_4$ (mg C-$CH_4$ $m^{-2}$ $d^{-1}$) |
|---|---|---|---|---|---|---|
| 0 | 290.49 | 1313.53 | 571.1 | 3021.12 | 81.83 | 1031.23 |
| 1 | 278.49 | 1280.02 | 556.53 | 2944.06 | 78.45 | 988.65 |
| 2 | 267.35 | 1247.57 | 542.42 | 2869.41 | 75.31 | 949.09 |
| 3 | 256.99 | 1216.13 | 528.75 | 2797.11 | 72.39 | 912.32 |
| 4 | 247.36 | 1185.68 | 515.51 | 2727.07 | 69.68 | 878.14 |
| 5 | 238.41 | 1156.19 | 502.69 | 2659.24 | 67.16 | 846.36 |
| 6 | 230.09 | 1127.62 | 490.27 | 2593.54 | 64.81 | 816.81 |
| 7 | 222.35 | 1099.96 | 478.24 | 2529.9 | 62.63 | 789.34 |
| 8 | 215.16 | 1073.15 | 466.59 | 2468.26 | 60.61 | 763.81 |
| 9 | 208.47 | 1047.2 | 455.3 | 2408.55 | 58.73 | 740.09 |
| 10 | 202.27 | 1022.05 | 444.37 | 2350.72 | 56.98 | 718.05 |
| 11 | 196.51 | 997.7 | 433.78 | 2294.7 | 55.35 | 697.59 |
| 12 | 191.16 | 974.11 | 423.53 | 2240.45 | 53.85 | 678.62 |
| 13 | 186.21 | 951.26 | 413.59 | 2187.9 | 52.45 | 661.04 |
| 14 | 181.62 | 929.13 | 403.97 | 2137 | 51.16 | 644.77 |
| 15 | 177.39 | 907.69 | 394.65 | 2087.69 | 49.97 | 629.73 |
| 16 | 173.48 | 886.93 | 385.62 | 2039.94 | 48.87 | 615.86 |
| 17 | 169.89 | 866.82 | 376.88 | 1993.68 | 47.86 | 603.1 |
| 18 | 166.59 | 847.34 | 368.41 | 1948.88 | 46.93 | 591.38 |
| 19 | 163.57 | 828.47 | 360.21 | 1905.49 | 46.08 | 580.66 |
| 20 | 160.81 | 810.2 | 352.26 | 1863.45 | 45.3 | 570.89 |
| 21 | 158.32 | 792.5 | 344.56 | 1822.74 | 44.6 | 562.03 |
| 22 | 156.07 | 775.35 | 337.11 | 1783.31 | 43.96 | 554.05 |
| 23 | 154.06 | 758.74 | 329.89 | 1745.11 | 43.4 | 546.9 |
| 24 | 152.27 | 742.66 | 322.9 | 1708.12 | 42.89 | 540.56 |
| 25 | 150.7 | 727.08 | 316.12 | 1672.28 | 42.45 | 535 |
| 26 | 149.35 | 711.99 | 309.56 | 1637.57 | 42.07 | 530.2 |
| 27 | 148.21 | 697.37 | 303.2 | 1603.95 | 41.75 | 526.15 |
| 28 | 147.27 | 683.21 | 297.05 | 1571.39 | 41.48 | 522.81 |
| 29 | 146.53 | 669.5 | 291.09 | 1539.85 | 41.28 | 520.19 |
| 30 | 145.99 | 656.22 | 285.31 | 1509.3 | 41.12 | 518.27 |
| 31 | 145.64 | 643.35 | 279.72 | 1479.71 | 41.03 | 517.04 |
| 32 | 145.49 | 630.89 | 274.3 | 1451.05 | 40.98 | 516.5 |
| 33 | 145.49 | 618.82 | 269.05 | 1423.29 | 40.98 | 516.5 |
| 34 | 145.49 | 607.13 | 263.97 | 1396.4 | 40.98 | 516.5 |
| 35 | 145.49 | 595.81 | 259.05 | 1370.35 | 40.98 | 516.5 |
| 36 | 145.49 | 584.84 | 254.28 | 1345.13 | 40.98 | 516.5 |
| 37 | 145.49 | 574.21 | 249.66 | 1320.69 | 40.98 | 516.5 |
| 38 | 145.49 | 563.92 | 245.18 | 1297.02 | 40.98 | 516.5 |
| 39 | 145.49 | 553.96 | 240.85 | 1274.1 | 40.98 | 516.5 |
| 40 | 145.49 | 544.3 | 236.65 | 1251.89 | 40.98 | 516.5 |
| 41 | 145.49 | 534.95 | 232.59 | 1230.39 | 40.98 | 516.5 |
| 42 | 145.49 | 525.89 | 228.65 | 1209.55 | 40.98 | 516.5 |
| 43 | 145.49 | 517.12 | 224.84 | 1189.38 | 40.98 | 516.5 |
| 44 | 145.49 | 508.62 | 221.14 | 1169.83 | 40.98 | 516.5 |
| 45 | 145.49 | 500.39 | 217.56 | 1150.9 | 40.98 | 516.5 |
| 46 | 145.49 | 492.42 | 214.1 | 1132.57 | 40.98 | 516.5 |
| 47 | 145.49 | 484.7 | 210.74 | 1114.81 | 40.98 | 516.5 |
| 48 | 145.49 | 477.22 | 207.49 | 1097.61 | 40.98 | 516.5 |
| 49 | 145.49 | 469.98 | 204.34 | 1080.94 | 40.98 | 516.5 |

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|---|---|---|---|---|---|---|
| 50 | 145.49 | 462.96 | 201.29 | 1064.8 | 40.98 | 516.5 |
| 51 | 145.49 | 456.16 | 198.33 | 1049.17 | 40.98 | 516.5 |
| 52 | 145.49 | 449.58 | 195.47 | 1034.03 | 40.98 | 516.5 |
| 53 | 145.49 | 443.2 | 192.7 | 1019.37 | 40.98 | 516.5 |
| 54 | 145.49 | 437.03 | 190.01 | 1005.16 | 40.98 | 516.5 |
| 55 | 145.49 | 431.04 | 187.41 | 991.4 | 40.98 | 516.5 |
| 56 | 145.49 | 425.25 | 184.89 | 978.08 | 40.98 | 516.5 |
| 57 | 145.49 | 419.64 | 182.45 | 965.17 | 40.98 | 516.5 |
| 58 | 145.49 | 414.2 | 180.09 | 952.67 | 40.98 | 516.5 |
| 59 | 145.49 | 408.94 | 177.8 | 940.55 | 40.98 | 516.5 |
| 60 | 145.49 | 403.84 | 175.58 | 928.82 | 40.98 | 516.5 |
| 61 | 145.49 | 398.9 | 173.43 | 917.46 | 40.98 | 516.5 |
| 62 | 145.49 | 394.11 | 171.35 | 906.46 | 40.98 | 516.5 |
| 63 | 145.49 | 389.48 | 169.34 | 895.8 | 40.98 | 516.5 |
| 64 | 145.49 | 384.99 | 167.39 | 885.47 | 40.98 | 516.5 |
| 65 | 145.49 | 380.64 | 165.5 | 875.47 | 40.98 | 516.5 |
| 66 | 145.49 | 376.43 | 163.67 | 865.79 | 40.98 | 516.5 |
| 67 | 145.49 | 372.35 | 161.89 | 856.41 | 40.98 | 516.5 |
| 68 | 145.49 | 368.4 | 160.17 | 847.32 | 40.98 | 516.5 |
| 69 | 145.49 | 364.57 | 158.51 | 838.52 | 40.98 | 516.5 |
| 70 | 145.49 | 360.87 | 156.9 | 829.99 | 40.98 | 516.5 |
| 71 | 145.49 | 357.28 | 155.34 | 821.73 | 40.98 | 516.5 |
| 72 | 145.49 | 353.8 | 153.83 | 813.74 | 40.98 | 516.5 |
| 73 | 145.49 | 350.43 | 152.36 | 805.99 | 40.98 | 516.5 |
| 74 | 145.49 | 347.17 | 150.94 | 798.48 | 40.98 | 516.5 |
| 75 | 145.49 | 344.01 | 149.57 | 791.22 | 40.98 | 516.5 |
| 76 | 145.49 | 340.95 | 148.24 | 784.18 | 40.98 | 516.5 |
| 77 | 145.49 | 337.98 | 146.95 | 777.36 | 40.98 | 516.5 |
| 78 | 145.49 | 335.11 | 145.7 | 770.75 | 40.98 | 516.5 |
| 79 | 145.49 | 332.33 | 144.49 | 764.35 | 40.98 | 516.5 |
| 80 | 145.49 | 329.63 | 143.32 | 758.16 | 40.98 | 516.5 |
| 81 | 145.49 | 327.02 | 142.18 | 752.16 | 40.98 | 516.5 |
| 82 | 145.49 | 324.5 | 141.09 | 746.34 | 40.98 | 516.5 |
| 83 | 145.49 | 322.05 | 140.02 | 740.71 | 40.98 | 516.5 |
| 84 | 145.49 | 319.68 | 138.99 | 735.26 | 40.98 | 516.5 |
| 85 | 145.49 | 317.38 | 137.99 | 729.97 | 40.98 | 516.5 |
| 86 | 145.49 | 315.16 | 137.02 | 724.86 | 40.98 | 516.5 |
| 87 | 145.49 | 313 | 136.09 | 719.9 | 40.98 | 516.5 |
| 88 | 145.49 | 310.91 | 135.18 | 715.1 | 40.98 | 516.5 |
| 89 | 145.49 | 308.89 | 134.3 | 710.45 | 40.98 | 516.5 |
| 90 | 145.49 | 306.93 | 133.45 | 705.95 | 40.98 | 516.5 |
| 91 | 145.49 | 305.04 | 132.62 | 701.58 | 40.98 | 516.5 |
| 92 | 145.49 | 303.2 | 131.83 | 697.36 | 40.98 | 516.5 |
| 93 | 145.49 | 301.42 | 131.05 | 693.27 | 40.98 | 516.5 |
| 94 | 145.49 | 299.7 | 130.3 | 689.3 | 40.98 | 516.5 |
| 95 | 145.49 | 298.03 | 129.58 | 685.46 | 40.98 | 516.5 |
| 96 | 145.49 | 296.41 | 128.87 | 681.74 | 40.98 | 516.5 |
| 97 | 145.49 | 294.84 | 128.19 | 678.14 | 40.98 | 516.5 |
| 98 | 145.49 | 293.33 | 127.53 | 674.65 | 40.98 | 516.5 |
| 99 | 145.49 | 291.86 | 126.89 | 671.27 | 40.98 | 516.5 |
| 100 | 145.49 | 290.43 | 126.28 | 668 | 40.98 | 516.5 |
| **AVG** | 159.58 | 569.53 | 247.62 | 1309.93 | 44.95 | 566.52 |

*AVG: Average over 100 years*

(Source: Derived using UNESCO/IHA Risk Assessment Tool - Beta version.)

**Degassing at the downstream of the reservoir outlet (s)**

Degassing is commonly estimated by calculating the difference between the gas concentration up- and down-stream of the dam, multiplied by the turbine discharge. For knowing the concentration of $CH_4$ which is produced from the sediments an experimental reservoir emission conditions form two type of soils namely Lichen humus and Moss humus has been considered and mean $CH_4$ emission for one year from this soils has been considered as the concentration of $CH_4$ which is released into the atmosphere in the form of degassing.

**Typical reservoir conditions**

| Conditions | Typical corresponding conditions in reservoir |
|---|---|
| T1A1P1 | Deeper zone. High humic substance. |
| T1A2P2 | Littoral zone during the cold season, all around circulated air through, low humic substance and low to direct decay of natural issue. |
| T1A2P1 | Littoral zone during the cold season, all around circulated air through, high humic substance or potentially exceptionally dynamic disintegration of natural issue. |
| T1A1P2 | Littoral zone during the cold season, low degree of broke down oxygen, low humic substance and low to direct decay of natural issue. |
| T2A1P2 | Aeration, dulow humic substance and low to direct decay of natural issue. |

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| | |
|---|---|
| T2A2P2 | Littoral zone throughout the late spring season, very much circulated air through, low humic substance and low to direct deterioration of natural issue. |

*MH- Moss Humus, LH-Lichen Humus (Source: Adapted from Tremblay, 2005)*

## V. Total Predicted Emission from Sardar-Sarovar RBPH

Total predicted diffusive flux from the reservoir is 12.51648 $CO_2$eq Tons/Year. At depths larger than approximately 20 m, the pressure is too high for bubbles to form so there only dissolved methane can exist. So that dissolved methane will enters into atmosphere as degassing at the downstream and the predicted methane emission 24.16508 $CO_2$eq Tons/Year from table. And the flux which are released from macrophytes are not been considered because it depends on the water quality and based on the atmospheric conditions that prevail over the reservoir. So the total predicted emission from the reservoir is equal to the sum of diffusive flux and emissions from degassing.

Total emission from the reservoir = diffusive flux + emissions of $CH_4$ in the form of degassing

= 12.516+ 24.166
= 36.682 T of$CO_{2eq}$/Year

A model for estimating the GHGs from storage based hydropower scheme. It discusses estimation of GHG emission using various components like bubbling, upstream diffusive flux, degassing, and downstream diffusive flux. It also discusses the technique of prediction of GHGs as well as its range throughout life cycle of the reservoir (100 years) with 67% level of confidence as recommended by UNESCO/IHA GHG risk assessment tool. Further the chapter discusses about the estimates of the contribution by bubbling and degassing.

## VI. Conclusion

- The Organic Matter originates generates very high in this flooded area, and it acts as the primary pollutant. And find out daily temperature, mean precipitation.
- In this flooded area release high quantity of $CO_2$ and $CH_4$.
- In These past 16 years data the amount of macrophytes are gradually increased.
- The Sardar sarovar dam storage capacity is very high, the water flowing from upstream to downstream level then seepage velocity also very high.

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