Estimating Greenhouse Gases Emissions from Karun-4 Water Reservoir by Applying G-res Model

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Abstract

Water reservoirs created by dams are known to be an important source of greenhouse gases (GHG) to the atmosphere but their quantitative significance is under debate. Models are helpful tools in estimating GHG in water reservoirs under different climate change scenarios. In this study, we applied G-res model that uses a conceptual framework built with scientists from the University of Quebec at Montreal, the Norwegian Foundation for Scientific and Industrial Research and the Natural Resources Institute of Finland. The novelty of this model is to integrate not only gross GHG flux to predict the role of a reservoir in atmospheric GHG but to take into account the natural situation before the impoundment. The estimate of the net GHG impact, based on the best prior knowledge and scientific reasoning available today, should help in identifying whether an existing reservoir or project in planning has a potentially high or low expected GHG footprint. This study aimed to calculate the carbon footprint in Karun-4 dam, an arch dam on the Karun River located at 180 km southwest of Shahr-e-Kord in the province of Chaharmahal and Bakhtiari, Iran. By integrating metrological and geographical data of the catchment and physical and chemical characteristic of water inflow GHG emissions in Karun-4 was quantified. We focused on G-res as a screening tool to identify projects with potentially significant emissions or with a high sensitivity to GHG emissions. Where significant emissions are predicted then further detailed modeling or measurement campaigns may be required to quantify the emissions more accurately.

Keywords: greenhouse gases (GHG), Karun-4 Dam, modeling, G-res

1. Introduction

Water reservoirs are artificial lakes and constructed on rivers to meet primarily purposes such as flood control, water supply, hydropower generation, or irrigation. Beside primary goals of the construction provide recreation (e.g., swimming, boating) or fishing. Water retention time and water body depth and volume vary distinctively among different water reservoirs. Reservoirs can be classified based on a) the location of the basin, b) the operation of the dam, and c) the hydraulic residence time. These three types of water reservoirs are tributary-storage reservoirs, run-of-the-river reservoirs, and main stem-storage reservoirs [1].

It has been shown that water reservoirs are a source of greenhouse gases (GHG) (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Although recent development of in precise GHG measurements in reservoirs there are uncertainties in the real estimation of the GHG budget in water reservoirs. There are two main reasons for these uncertainties: i) GHG fluxes are measured by different methods (e.g., floating chamber, thin boundary method, eddy covariance tower, acoustic methods, and funnels). Several methods do not capture ebullition events (e.g., air-water gas exchange) or exclude ebullition due to interfering with the linear accumulation of CH_4 in the sampling chamber. ii) Temporal and spatial variation of aquatic GHG fluxes is high. For instance, CH_4 ebullition measured by funnel traps is deployed for a relatively short period in a relatively limited number of locations. However, it is not convenient to estimate both temporal and spatial variability of fluxes [2].

Over the last decade advances in measuring precise GHG fluxes had happened but still, it remains challenging for scientists to estimate GHG budget for water reservoirs from observations. The main reason for this challenge is a short observational time series to predict interannual-to-decadal variability of water reservoirs budget. Models can be used to fill some gaps in observations and estimate long-term GHG budgets. Previously, to estimate GHG budget of water reservoirs to national inventories an average was calculated. This method is problematic because we already know that each reservoir may have a different GHG impact and we should be able to consider all differences.

The G-res tool was launched today at the 2017 World Hydropower Congress in Addis Ababa. G-res enables decision-makers and stakeholders to better estimate the greenhouse gas emissions associated with the introduction of a reservoir into a landscape. This model builds on a conceptual framework developed by researchers from the University of Québec at Montreal (UQÀM), the Norwegian Foundation for Scientific and Industrial Research (SINTEF) and the Natural Resources Institute of Finland (LUKE). It utilizes a new modeling methodology based on current scientific knowledge and over 500 empirical measurements from over 200 reservoirs worldwide.

Something novel about the G-res tool will be its ability to attribute impacts among the various services which a reservoir provides. This is very important because most reservoirs are multipurpose reservoirs. They aren't made just to provide hydropower, but also for irrigation, navigation, flood protection, and often many other purposes. So it will be important to attribute GHG impacts to each different service. Another innovative feature of the G-res tool is its ability to calculate the net impact of a future reservoir on the GHG regime of a particular site. This is a significant breakthrough. The net impact is a comparison of the GHG regime in the landscape before the reservoir was impounded with the new GHG regime after impoundment. It's the difference between the two that tells us the actual impact of that reservoir.

In the first studies, hydroelectric power was considered as a carbon-free source of energy (i.e.[3]). Rudd et.at., for the first time, concluded that the greenhouse gas production per unit of power generated is not zero [4]. It is urgent to give some overall assessments to evaluate whether hydropower is an optimal choice for a low carbon path. The carbon footprint is a measure of the exclusive total amount of CO_2 equivalent emissions that are directly and indirectly caused by an activity or accumulated over the life stages of a product [5]. In particular, calculating the carbon footprint through a hydropower station's life cycle can quantificational estimate the total carbon emission and benefits comparing with power generation from fossil fuel. However, it seems necessary to calculate the carbon footprint for dams in Iran to compare their energy generation with other form of energy sources in terms of GHG production. I this study we focused on Karun-4 reservoir to investigate on y GHG balance by using G-res model that is recommended international hydropower association (IHA).

2. Methods

2.1 (G-res) Tool

The G-res tool was developed by the International Hydropower Association (IHA) based on the recommendation from the Intergovernmental Panel on Climate Change (IPCC) and can calculate the net carbon footprint of freshwater reservoirs [6]. The G-res tool is unique in its attempt to represent only the GHG emissions that are attributable to the introduction of the reservoir in a catchment.

The calculation of net emissions in G-res includes four parts as mentioned in the following equation:

Net GHG emissions = [Post-impoundment GHG balance from the catchment after the introduction of a reservoir] – [Pre-impoundment GHG balance of the catchment before the introduction of a reservoir] – [Emissions from the reservoir due to Unrelated anthropogenic sources] + [GHG due to construction][7, 8]

is obtained from the semi-empirical model based on flux observations from 223 in this equation the post-impoundment GHG balance include all flux pathways (i.e. diffusion, bubbling, degassing, etc.) into the atmosphere after introducing the reservoir and inundation of adjacent areas of the river. This calculation reservoirs around the world [9].

The emissions within the landscape before introducing the reservoir is referring to pre-impoundment. The reservoir area is generated based on 30m spatial resolution SRTM digital elevation data [8] via an earth engine after inputting the exact coordinates of the dam and the normal operating level above sea level [7]. Then the land types within the reservoir area are estimated using 300 m spatial resolution ESACCI land cover data. The last procedure is multiplying the surface area of each land type with the corresponding emission factor for both CO_2 and CH_4 [10].

Unrelated anthropogenic sources (UAS) mean the carbon emissions in the reservoir area due to sewage from anthropogenic activities should be removed. Here the input is the catchment area, which is the scope of land where precipitation collects and drains off into a common outlet. In our study, the catchment area equals to the upstream watershed region controlled by the dam. Community and industrial activities which occur in the catchment area make contributions to nutrients and carbon flowing into the reservoir. This part of emissions is reconstructed by using a share of phosphorus load exceeding the natural background load as a proxy [10]. Land types within the catchment area are needed to estimate the natural background load and high or low land-use intensity is set manually to represent anthropogenic activities. The construction term refers to the emissions related to the production of materials, transport and plant stages to build the dam and other associated infrastructure, which are calculated from the consumption of material and power, as well as corresponding emission factors [10]

2.2 Study site

The Karun-4 Dam is an arch dam on the Karun River located at 180 km southwest of Shahr-e-Kord in the province of Chaharmahal and Bakhtiari, Iran (figure 1). The Karun has the highest discharge of all the Iranian rivers.[3] Its construction is aimed at an electric power supply of 2107 million kWh annually and controlling floods in the upper Karun.

Figure 1: map of location of Karun-4 dam in Iran

The dam is a concrete double curvature arch-type and 230 meters high from the foundation. The arch dam design is an ideal one for a dam built in a narrow, rocky gorge to hold back water in a reservoir. The dam is curved. Because of the arch shape, the force of the backed-up water presses downward against the dam and has the effect of strengthening the dam foundation. The dam withholds a reservoir with a surface area of 29 square kilometers and a capacity of 2.19 cubic kilometers. The dam's first study was conducted in 1995 and river diversion began in 1997. Concrete pouring began in 2006 and the power plant began producing electricity in November 2010. On December 11, 2010, the second generator for the dam became operational and was connected to the grid.

Table 1: Main parameters of Karun-4 dam

Coordinates	31°35′58″N 50°28′20″E
Construction began	1997
Opening date	2010
Impounds	Karun River
Height	230 m
Length	440 m
Spillway capacity	6,150 m^3/s
Total capacity	2,190,000,000 m^3
Catchment area	12,813.4 km^2
Surface area	29 km^2
Installed capacity	1,020 MW

Figure 2: Arial view of Karun 4 reservoir

Figure 3: location of catchment (gray area) and dam (red point)

There are 3 main objectives for this dam including a) to produce average annual hydropower energy as much as 2100 GW-h. b)to join the cascade dams on the Karun River, hence regulate the flow to supply the water required by the industry and agriculture downstream. c) to control the destructive floods of the Karun River.

3. Results and Discussion

3.1 Pre-impoundment GHG balance before dam construction

Before impoundment of the landscape by the reservoir different ecological sub-units exist and have their GHG balance. The behavior of each particular sub-unit is highly dependent on land-use intensity. For example, while a piece of the forest generally absorbs CO_2 from the atmosphere through photosynthesis, wetlands not only deposit that carbon as peat but also typically emit CH_4. Similarly, natural streams, rivers, and lakes tend to emit both CO_2 and CH_4.

Based on the soil type map provided by earth engine [10], the catchment in this study resides on non-waterlogged, mineral soils without organic soils. Grassland makes a substantial share in the land cover before the introduction of the reservoir.

Annual CO_2 and CH_4 in pre-impoundment were 33 And 0 tCO_2e/year respectively. The main reason for no CH_4 emission before introducing the reservoir could be high oxygen level in the water. This could lead to the oxic layer in the bottom layers of the river that inhibit methanogenesis activity by the bacteria.

Table 2: land cover type and the correspondent GHG balance of the inundated area by the reservoir

Land cover type	Percentage (%)
Grass land/scrubland	76.18
Bare areas	1.8
Water bodies	17.7
Crop lands	4.32
Forest	0
Settlements	0
Areal CO_2emission rate (tCO_2e/year)	33
Areal CH_4 emission rate (tCO_2e/year)	0

3.2 Post-impoundment GHG balance of the reservoir

To find out the original composition of the inundated landscape in G-res tool the buffer method is applied. This method evaluates the land cover of a buffer zone around the reservoir, measuring 25% of the equivalent spherical diameter (analogous to the method of Heathcote et al. 2015). This approach was validated using about 200 reservoirs for which satellite images from both pre- and post-impoundment period were available [7, 11].

There are three main pathways for GHG emissions in water reservoirs including molecular diffusive, ebullition and degassing. From the empirical model in G-res tool, CH_4 diffusive flux is mainly depended on temperature and spatial parameters of the reservoir while CO_2 diffusive flux is also controlled by surface soil carbon content [12]. Second gas transportation pathway when an insoluble gas (e.g., CH_4) produced in sediment cannot be dissolved in water and consequently produced bubbles emit into the atmosphere by ebullition [13]. Furthermore, When water undergoes rapidly depressurization or aeration dissolved gases can be emitted. After the water passes through the turbines GHG gases can be emitted into the atmosphere or can be absorbed by microbes (e.g., CH_4 oxidation by methanotrophic bacteria). Large degassing emission are expected when GHG content in spilled water is high.

Table 3 lists the total flux rate of CO_2 and CH_4, as well as the fraction of CH_4 in the post-impoundment stage. Furthermore, it displays pathways in CH_4 fluxes and their contribution to each one. In this estimation molecular diffusion has the highest value in CH_4 emission and degassing through turbines contributes the lowest in CH_4 emission.

Table 3: Post-impoundment GHG fluxes of Karun-4 reservoir

Total emission rate (tCO_2e/year)	2647
CO_2 release rate (tCO_2e/year)	2500
CH_4 release rate (tCO_2e/year)	147
- in which diffusive flux (%)	79
- in which degassing (%)	7
- in which bubbling (%)	14

3.3 Emissions from the Reservoir Due to UAS

UAS refers to unrelated anthropogenic sources of GHG in the catchment. The purpose of this concept is to separate the anthropogenic sources of nutrients, carbon and direct GHG emissions via inflow water from those occurring directly from inundating the landscape. The sewage from all anthropogenic activities will finally flow into the reservoirs through branches, which accounts for part of the total emission of post-impoundment.

Table 4 displays the CH_4 release rate due to UAS, where the water residence time means the average amount of time that a molecule of water spends in the reservoir. The results are also clustered into two classifications depending on their climate background and population density.

Table 4: Unrelated Anthropogenic Sources (UAS) of GHG in the catchment

Water residence time (year)	1.6
CH_4 release rate due to UAS ($gCO_2e/m^2/year$)	5
- in which from land use (%)	32
- in which from sewage (%)	68
UAS/Post-impoundment CH_4 release (%)	65

Water residence time is 1.6 years in Karun-4 reservoir. When water residence increases in a reservoir, GHG fluxes may escalate. About 65% of CH_4 emissions of the reservoir is due to UAS. Community and industrial sewage in the catchment my flow into the reservoir and this process has the potential increases nutrient concentration. In this condition, GHG emissions increase drastically. In G-res model it is estimated that about 65% of CH_4 emission of the reservoir is due to these anthropogenic changes. About 68% of this increase is due to community sewage and about 32% is because of land management such as agriculture and forestry (Table 4).

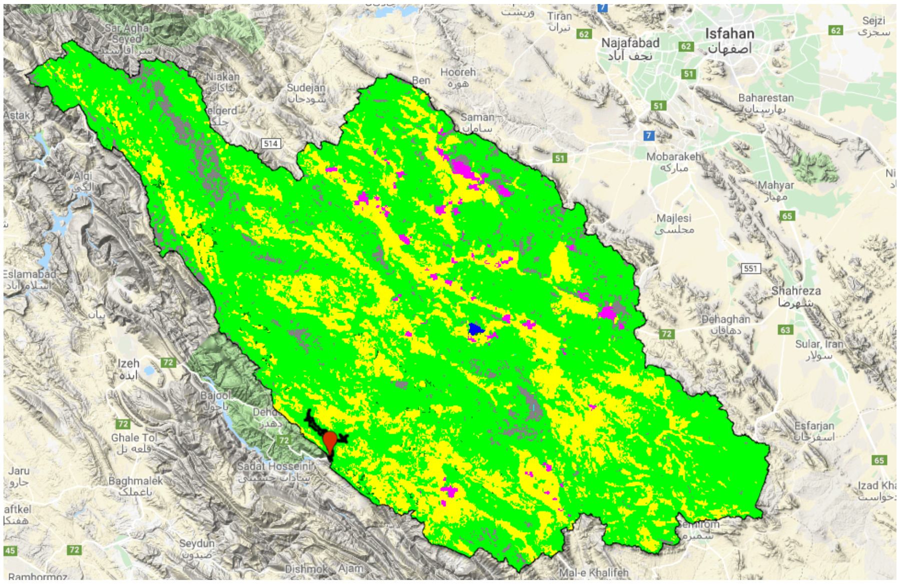

Figure 4: *Land cover and land use types in catchment areas* for Karun-4 reservoir

Croplands 🟨 Water bodies 🟦 Bare areas ▩

Settlements 🟪 Grassland 🟩

3.4 Net GHG Footprint

Net GHG footprint is the sum of the above four parts according to Equation (1). Table 7 presents the annual reservoir wide emission rate of GHG for pre/post-impoundment and UAS emission. In this model, GHG emission over the construction process is ignored. Comparing with emissions from overall construction, the annual balance of the rest items is quite small [12].

GHG emissions before the dam introduction into the catchment are low (33 tCO_2e/year) but after the reservoir was constructed this GHG increased about 80 times (2647 tCO_2e/year). Furthermore, GHG emissions due to human activities in the catchment area 69 tCO_2e/year. This shows that about 2.6% of total net GHG emissions are due to human activity and this amount is low.

Table 5: 7. Annual reservoir emission rate of GHG for pre/post-impoundment and UAS

Post-impoundment (tCO_2e/year)	2647
Pre-impoundment (tCO_2e/year)	33
UAS (tCO_2e/year)	96

4. Conclusion

Integrated G-res tool is used to conduct analysis, which considers three parts of emission balance, including pre-impoundment, post-impoundment and UAS. Accounting for the strict requirement for model inputs, a general procedure is proposed to prepare input variables based on multi-source geographic datasets, consisting of land cover maps, digital elevation models and satellite images, as well as construction planning documents for each site. Three main conclusions are summarized:

- Pre-impoundment GHG emissions are very low and dam introduction into the catchment increased about 80 times GHG emissions.
- Human activities have very limited effects on the GHG balance of the reservoir (2.6% of total emissions).
- CO_2 emissions of the reservoir are about 17 times higher than CH_4 emissions and CO_2 is the main GHG in this reservoir.

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