ATMOSPHERIC CARBON DIOXIDE SEQUESTRATION TROUGH KARST DENUDATION PROCESSES Estimated from Indonesian Karst Region

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Abstract

The important of karst denudation in term of climate changes lies on the ability of karst ecosystem in regulating atmospheric carbon. Karst denudation consumes CO₂ either from atmosphere and soils. This paper is intended to describe the karst denudation related to CO₂ sequestration and apply the concept to calculate carbon gain through karst denudation process in Indonesian. Estimated from the carbonate rock outcrops, the Indonesian karst region is approximately 140,000,000 km². Previous work suggested that average denudation rate of Indonesian karst is 82.9 m³/year/km² or equivalent to 218,856 kg/year/km². Since 120 kg of atmospheric carbon is absorbed during the removal of one ton calcium carbonate removal and Indonesia karst area is 140.000 km², Indonesian karst area up takes 3,677 Gg/year atmospheric carbon. This amount is equivalent to 13.482 Gg CO₂/year. This figure is merely from denudation processes, considering carbon dioxide sequestration by karst vegetation covers will inevitably gains much higher number. The role of karst denudation therefore needs more attention in carbon flux calculation and developing climate change mitigation measures

Keywords: Karst denudation, karstification

Introduction

CO₂ is one of the important green house gases of which has big contribution to global warming. In recent decades, emissions of CO₂ have continued to increase (Dawson and Spannagle, 2009; Mackenzie, 2004; Parry et.al., 2007). The increase is mainly caused by fossil fuel and land use changes. Global annual fossil CO₂ emissions increased from an average of 6.4 ± 0.4 GtC/yr in the 1990s to 7.2 ± 0.3 GtC/yr in the period 2000 to 2005. Estimated CO₂ emissions associated with land use change, averaged over the 1990s, were 0.5 to 2.7 GtC/yr, with a central estimate of 1.6 Gt/yr (Parry *et.al.*, 2007).

Terrestrial and oceanic carbon sequestration potentials therefore are needed, to counter balance the increase of CO₂ emission. Karst ecosystem is one of the carbon sink potentials. Karst landscape systems, composed primarily of limestone and dolomite, cover some 12% of the earth's land surface, and weathering of these rocks on the continents has been recognized as a sink term for atmospheric CO₂ (Ford and Williams, 2007; Gornitz, 2008). It owes its important not only because it stores carbon binding rocks but also because karstification itself is a carbon dioxide sequestration process.

Karst processes are part of the world carbon, water and calcium cycles that occur at the interfaces between lithosphere, hydrosphere, atmosphere and biosphere. The CO₂-H₂O-CaCO₃ reaction is known as karst dynamic system which is useful in explaining the important of karst in carbon cycle (Yuan, 2002; Grove, 2001; Liu and Zhao, 2000; Liu *et al.*, 2010). Karst study has an important role in understanding the global carbon cycle, and thereby can contribute more to an understanding of global climate change.

The important of karst denudation in term of climate changes lies on the ability of karst ecosystem in regulating atmospheric carbon. Karst denudation consumes CO₂ either from atmosphere and soils. Thereafter this paper is intended to describe the karst denudation related

to CO₂ sequestration and applying the concept to calculate carbon gain in Indonesia Karst Region through karst denudation process. Calculation was based on data from previous works.

Indonesian Karst Region

Karst areas of Indonesia develop mostly in limestone outcrops, small areas develop in dolomites and marble. It covers an area of 140.000 km² from 95°21' to 140°96' East Long; and from 10°37' South Lat to 5°57' North Lat. No karst area is reported to develop in non carbonate rocks. Carbonate rock distribution of Indonesia is controlled by tectonic frameworks of Indonesia archipelago resulted from colliding Hindia-Australia in the south, Pacific Plate in the east, and Philippine Plate in the north to the Eurasia plate (Hall and Blundell, 1996; Hamilton, 1979; Verstappen, 2000). Those four plate interaction have brought about orogenetic processes that made carbonate rocks to outcrop. Most carbonate outcrops are associated with convergence margin. Only Papua karst areas (easternmost part of Indonesia) are not related to convergence margin.

Figure 1. Indonesian karst areas compiled from geological map of Indonesia
(From: Indonesian Geological Survey)

Most limestone and dolomite formation are deposited during Tertiary. However, small areas of Cretaceous limestone formations are also discovered in the high mountain of Papua. Quaternary carbonate outcrops are quite common in Indonesia archipelagoes, especially along cost lines and small islands as a result of neo-tectonically uplift. Due to subject to high intensity of tectonic deformation, carbonate outcrops are severely fractured giving a better prerequisite for karst development. Karst areas of Indonesia are distributed either slightly or in the high mountain ranges up to more than 4,000,000 meters above sea level.

Karst Denudation

Denudation of karst areas in Indonesia is significantly favoured by the high yearly precipitation and the existence of overlying forest coverage. Though rainfall is varies in some localities, 2000 up to more tjam 3000 mm annual rainfall is quite common in the area. Torrential rainfall of monsoonal climate and tropical climate has very important roles in

denudation processes. The high fractured carbonate rocks as mention earlier is the other factor make possible denudation of Indonesian karst is quite intensive. Forest cover (although in some areas have been deforested) on the other hand provides high concentration of soil CO_2 and furthermore resulting in more aggressive water to dissolve limestone. Those circumstances should be the explanation why karst morphology in the forms of cockpits, conical karst, and tower karst are easily encompassed throughout Indonesian archipelago, though most of Indonesian karst areas have just been subject to karstification since Late Pliocene. Compared to Dinaric Karst, Guilin Karst, and Mammoth Cave, Indonesia karst is much younger.

Denudation rate of Indonesian karst was first calculated by Balazs (1971) by using Corbel's method. He investigated five sites of Indonesian karst, i.e Gunung Saribu Karst (Sumatra), Kalapanunggal Karst (Java), Gunung Sewu Karst (Java), Nusa Barung Karst (Java), and Maros Karst (Sulawesi). Denudation rates of those areas are summarized in Table 1. With the same method, Balazs (1971) calculated denudation rate of temperate karst of Hungary for comparison of which the result was $20.4 \text{ m}^3/\text{year}/\text{km}^2$. Balazs's estimate clearly shows that denudation rate of Indonesian karsts is considerable high. This should be the reason accounts for the well developed karst landforms within young karst rocks of Indonesia. Further research (by Karst Reseach Group-Faculty of Geography UGM) is still ongoing to elaborate Balazs estimate, especially in understanding temporal variability of dissolved carbonate brought from Indonesian karst and its relation to carbon cycle.

Table 1. Denudation rates of some Indonesian Karst Areas

Karst Area	Denudation rate	
	$\text{m}^3/\text{year}/\text{km}^2$	mm/year
Seribu Karst	> 63	
Nusa Barung Karst	No data	No data
Kalapanunggal	99	0.099
Gunung Sewu Karst	86	0.086
Maros Karst	83	0.083
Average	82.9	0.0829

(From Balazs, 1971)

Carbon sequestration

Since karst areas develop under soluble rock, the major denudation process in the area is dissolution. Dissolution is of paramount importance in developing karst compared with its relatively minor role in other lithologies. The dissolution is incorporated by the absorption of atmosphere carbon dioxide. Atmosphere CO_2 along with rain enters the karst system acting as dissolve agent and generating denudation processes. Carbon dioxide is the most soluble of the standard atmospheric gases, e.g. 64 times more soluble than N_2 . The dissolution process is started through reaction between water and CO_2 in the form of H_2CO_3 . H_2CO_3 is unstable and breaks down in H^+ and HCO_3^- . H^+ ion then replaces Ca in the limestone (CaCO_3) producing Ca^{2+} and CO_3^{2-} to the bulk solution. Ca^{2+} and CO_3^{2-} ions released from the surface of the mineral must be transported away into the bulk of the solution by molecular diffusion. On the other hand, CO_2 , H_2CO_3 , and H^+ must migrate from the bulk to the mineral's surface. Thus one molecule of CO_2 is consumed to dissolve one CaCO_3 unit (Figure 2).

Figure 2.
Sequestration of CO₂ in karst denudation
through carbonate dissolution (Modified
from Dreybroadt, 2004)

Carbonate rock dissolution have assumed that half of the dissolved inorganic carbon leaving a given catchment comes from the mineral and half from the atmosphere. Hence 120 kg carbon is absorbed from atmosphere during the removal of 1000 kg carbon through karst denudation. As mentioned earlier, karst denudation rate in Indonesia is 82.9 m³/year/km². Considering average limestone specific gravity of 2,640 kg/m³, carbon uptake from atmosphere during karst denudation equals to 218,856 kg/year/km². Since the area of Indonesian karst is 140,000 km², thus total carbon sequestration during karst denudation is 3,677 Gg/year or equivalent to **13,482 Gg CO₂/year**. To give general figure on the important karst ecosystem in atmospheric carbon sequestration, DHG emission is presented in Table 2 for comparison.

Table 2. Summary of GHG emission and removal (in Gg)

Source/Sink	CO ₂ Emission	CO ₂ Removal	CH ₄	N ₂ O	CO ₂ Eq
Energy	305,983		1,221	6	335,540
Industry	31,938		104	0	34,197
Agriculture	2,178		2,419	72	75,419
Land Use Change and Forest	1,060,766	411,593	3	0	649,254
Peat Fire	172,000				172,000
Waste	1,662		7,020	8,05	151,578
TOTAL					1,415,988

From : MoE, 2009

Compared to green house gas (GHC) emission of Indonesia (Table 2), the role of karst denudation seems very important in atmospheric carbon dioxide sequestration. Karst denudation from Indonesian is able to up take a half of CO₂ emitted from industry. Considering carbon sequestration through biomass production, Indonesian Karst ecosystem, which covers approximately 8 percent of Indonesian landmass, must have much higher carbon sink potential.

Concluding Remarks

General figure from karst denudation in Indonesia obviously indicates that greater attention should be devoted to understand karst ecosystem in climate change mitigation. The important of karst denudation in term of climate changes lies on the ability of karst ecosystem in regulating atmospheric carbon through denudation processes. Karst denudation up takes CO₂ both from atmosphere and soils. Considering carbon sequestration through biomass production, Indonesian Karst ecosystem accordingly owes considerable role in climate change mitigation. Therefore, attempts should be made to ascertain comprehensive carbon cycle mechanism in karst ecosystem including carbon cycle from biomass production and other biological activities.

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