ATMOSPHERIC CARBON DIOXIDE SEQUESTRATION TROUGH KARST DENUDATION PROCESS Preliminary Estimation from Gunung Sewu Karst

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Abstract

Karst ecosystem is known as one of the major terrestrial carbon sinks on the earth. It owes its important not only because it stores carbon binding rocks but also because karstification itself is a carbon dioxide sequestration process. The paper documented here is an estimation of carbon dioxide sequestration under karst denudation process. Denudation rate was acquired from previous works suggesting that denudation rate of Gunung Sewu Karst is $50.91 \text{ m}^3/\text{year}/\text{km}^2$. Taking account the area of Gunung Sewu Karst as 1300 km^2 , total calcium carbonate removed from the area is 165.464 ton/year. Every tonne of limestone dissolved, 0.12 ton of atmospheric carbon is absorbed. In total, Gunung Sewu Karst up takes 19,855.68 ton carbon per year or equivalent to 72.804.16 ton/year atmospheric carbon dioxide. This figure is only from denudation process. Considering carbon sequestration through biomass production through agricultural practices, Gunung Sewu Karst ecosystem and other karst areas of Indonesia accordingly owes considerable role in climate change mitigation.

Keywords : Gunung Sewu Karst, Carbon Sequestration, Karst Denudation

A. Introduction

CO_2 is one of the important green house gases of which has big contribution to global warming. In recent decades, emissions of CO_2 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 CO_2 emissions increased from an average of $6.4 \pm 0.4 \text{ GtC/yr}$ in the 1990s to $7.2 \pm 0.3 \text{ GtC/yr}$ in the period 2000 to 2005. Estimated CO_2 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 CO_2 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 CO_2 . (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 $\text{CO}_2\text{-H}_2\text{O-CaCO}_3$ reaction is known as karst dynamic system which is useful in explaining the important of karst in carbon cycle (Daoxian, 2002; Grove, 2001; Liu and

Zhao, 2000). 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 Karst Gunung Sewu through karst denudation process. Calculation was based on previous works.

B. The Setting of Gunug Sewu Karst

Gunung Sewu karst is situated in three provinces, i.e. Yogyakarta, Central Java, and East Java Province, stretching 85 km west-east from Parangtritis Beach of Yogyakarta Special Province to Teleng Ria Beach of Pacitan-East Java. Its north-south width varies between 10 and 29 kms with approximate area of 1300 km². The Gunung Sewu karst is adjacent to the Indian Ocean on the south central coast of Java (Figure 1). Elevation range is between zero and 512.5 m above mean sea level, and the highest portions centrally located about 25 km from the cost line.

Figure 1. Landsat ETM depicting Gunung Sewu Karst and the surrounding areas

The prevailing contemporary climate in the Gunung Sewu karst is strongly influenced by the Northwest and Southeast monsoons, which produce a distinct wet season from October to April and a dry season, which may be extremely arid, between May and September. The annual rainfall, recorded from 14 local rain gauge stations between 1960 and 1997 varies between 1500 mm and 2986 mm annually. Mean annual temperature is about 27° C (Haryono and Day, 2004). The Gunung Sewu karst is made up of Neogen (Middle Miocene and Upper Pliocene) limestone the so-called Wonosari-Punung Formation. The limestone is composed of massive coral limestone in the south and bedded chalky limestone in the north (Balazs 1968; van Bemmelen 1970; Waltham *et al.* 1983; Surono *et al.* 1992; Rahadjo *et al.*, 1995). Total thickness of the limestone exceeds 650 m. The coral reef limestone is lithologically highly variable, but

dominated by *rudstones*, *packstones*, and *framestones*. Biohermal structures are identifiable, and lenses of volcanic ash are interspersed among the carbonates (Waltham *et al.* 1983). The bedded, chalky limestone become more prominent towards the north and northeast, and dominates the Wonosari Plateau.

The entire karst area of Gunung Sewu is cultivated. Limited land in the area has made farmers to plant any crops in any plot of land. Even farmers extend their cultivated land up to the hill tops. To cope with shallow soils or bedrock, farmers trap the sediments/soils transported by runoff during rainy season by establishing terraces on the hill slopes, therefore farmer get more areas of soil covered land. Crops in this case are grown in the soil that is already trapped in terraces. Terraces are constructed by piling up limestone boulders crashed from karren (Haryono, 2005).

Crop productivity, not to mention, is low. Productivity of some crops grown in Gunung Sewu karst is presented in Table 1. Two cope with this situation, multiple seasonal cropping and multiple perennial crop utilization types are employed. Long adaptation has brought about this land utilization types (Haryono, 2005).

Table 1. Productivity of crops grown in Gunung Sewu Karst, sampled from karst area of Paranggupito District (in quintals/hectare)

Seasonal Crops	Productivity	Perennial Crops	Productivity
Rain-fed rice	59.4	Coconut	55.0
Maize	144.0	Clove	2.0
Cassava	477.1	Cashew nut	6.23
Ground nut	16.1	<i>Gnetum gnemon</i>	10.9
Soybean	223	Coffee	3.1

From: Office of Agricultural Affair of Winger Regency, 2004

C. Karst Denudation and Carbon Sequestration

1. General Concepts

Karst is the term used to describe a special style of landscape containing caves and extensive underground water systems that is developed on especially soluble rocks. (Ford and Williams, 2007). A soluble rock is the first prerequisite for the development of karst. It includes limestone, dolomite, marble, halite, and gypsum (Ford and William, 2007; Palmer, 2007; White 2008). However in the case Indonesia, the greatest portion of soluble rock is limestone and just a small percentage is dolomite.

Since karst areas develop under soluble rock environments, 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 CO₂ 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 N₂. The dissolution process is started through reaction between water and CO₂ in the form of H₂CO₃. H₂CO₃ is unstable and breaks down in H⁺ and HCO₃⁻. H⁺ ion then replaces Ca in the limestone

(CaCO_3) and Ca^{2+} and CO_3^{2-} is released 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 CO_2 in karst
denudation through carbonate
dissolution (Modified from
Wolfgang, 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 uptakes from atmosphere during the removal of 1000 kg carbon through karst denudation.

2. Denudation and carbon sequestration in Gunung Sewu Karst

The calculation of karst denudation documented in this paper is based on Corbel (1956) formula (Formula 1).

$$V = \frac{4 \text{ ET}}{100} \quad (1)$$

Where

V : Denudation rate by dissolution ($\text{m}^3/\text{year}/\text{km}^2$)

E : *Run off* (Precipitation – Evaporation) in decimeter (dm)

T : CaCO_3 concentration in water discharged by karst springs (mg/l)

The average precipitation in Gunung Sewu Karst is **2.051 mm/year**. This figure was analyzed from 32 rain gauge stations recorded from 1945 to 2002 period. The averaged precipitation was calculated through isohyets method by using Arc-GIS software. On the other hand, evapotranspiration was estimated by Throunhtwaite (1955) method. The annual potential evapotranspiration (PET) of Gunung Sewu Karst is **1.362,91 mm**. Temperature used for PET calculation was based on Wonosari weather

station. Thus the annual runoff discharging from Gunung Sewu Karst is **688** mm. This figure is resulted from simply subtracting precipitation by evapotranspiration.

The carbonate concentration used in this paper is based on measurement in 22 springs conducted by Wijayanti (2002) Rini (2003). The carbonate concentration in water discharging by karst Springs in Gunung Sewu is summarized in Table 2. The concentration is bulk concentration without considering carbon source or sink that may take places within the Gunung Sewu Karst area. As it was described earlier that dissolution processes in karst areas is absorbed CO₂ from atmosphere and soils respired by biological decomposition. Inferring from Table 2, average CaCO₃ removed from Gunung Sewu Karst is **185** mg/l.

Table 2. Dissolved CaCO₃ discharging from karst Springs in Gunung Sewu Karst

No	Mata Air	CaCO ₃ (mg/l)
1	Sumber Praci	135
2	Sumber Beton	176
3	Sumber Waru	210
4	Sumber Nangari	158
5	Sumber Sambiroto	95
6	Sumber Weru	327
7	Sumber Beji	93
8	Sumber Teleng	203
9	Sumber Pule	145
10	Sumber Kali Suci	93
11	Sumber Bendungan	83

No	Mata Air	CaCO ₃ (mg/l)
12	Sumber Ponjong	249
13	Sumber Nggremeng	156
14	Sumber Beton	200
15	Sember Kenteng	231
16	Sumber Bendungan	173
17	Sumber Selonjono	231
18	Sumber Petoyan	206
19	Sumber Banyumudal	234
20	Sumber Kalitangis	220
21	Sumber Mbeji	218
22	Sumber Kalicacahan	240

Summarized from Wijayanti (2002) and Rini (2003)

Putting the runoff and average calcium carbonate concentration in Formula 1, the denudation rate of Gunung Sewu Karst is estimated to be **50,91** m³/km²/year. For the whole area of Gunung Sewu (1300 km²), this number is equivalent to **165.464 ton** CaCO₃/year. This number is also carbon dioxide uptake from denudation process. Comparing with denudation rate in Tatrac-East Alp (60), Batu Cave-Malasya (48,5), Carpathes-Ukraine(69,7), Lapoic-Norway (56-123), denudation rate estimation mentioned above seems reasonable. Hence, the estimate annual carbon dioxide sequestration in Gunung Sewu Karst through denudation processes is **72.804.16** ton. This number, one again, is merely from denudation process. Considering the considering carbon up takes by vegetation will inevitably gains much higher number. Different from other ecosystem where CO₂ respiration through vegetation and organic decomposition is emitted, karst ecosystem otherwise uptakes all CO₂ resulted from respiration. Only small portion of CO₂ is emitted to the atmosphere trough precipitation of calcite or aragonite during the formation of speleothems. The most portion of the CO₂ is brought to ocean in the form of bicarbonate ion.

D. Concluding Remarks

General figure from karst denudation in Gunung Sewu karst 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, Gunung Sewu Karst ecosystem and other karst areas, that cover approximately 15 percent of Indonesian landmass, 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 in general or specifically from agricultural practices.

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