Rates of Sediment Deposition in Lam Phra Phloeng Dam , Nakorn Ratchasima Province, Thailand, Using ^{210}Pb as a Geochronometer

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Abstract

Lam Phra Phloeng dam, Nakhon Ratchasima Province, is one of the most seriously affected by soil erosion related sedimentation dam in Thailand. Deforestation and rapid land use change, from forest to agricultural land, has led to increase sediment load in rivers draining into the dam. The dominant crops in the upper catchment are sugar-cane and cassava. After the crop has been harvested the land is tilled and becomes sensitive to sheet erosion. As a direct result the dam has become very shallow and its storage capacity was reduced rapidly. In this study, the constant initial concentration (CIC) of unsupported ^{210}Pb model was successfully used to assess sedimentation rate from ^{210}Pb profile data of eight sediment cores from Lam Phra Phloeng dam. The ^{210}Pb based apparent sediment accumulation rates ranged from 0.21 to 1.02 g/cm^2/yr with the average of 0.51 g/cm^2/yr compatible to the total sediment loaded to the river of 5.491×10^4 metric ton/yr and corresponding to the erosion rate of 2.27 mm/yr. Most of the sediment, more than 50%, was deposited at the distance of 3-5 km from the head of the reservoir. Such sediment distribution behavior was described based on the direction and velocity of the stream current. This study thus demonstrated the potential use of nuclear technique for water resource and erosion control management.

Key words: Lam Phra Phlong dam, sediment accumulation, ^{210}Pb

INTRODUCTION

One of the main problems of the water resource development program in Thailand is the sediment accumulation, which reduces the useful capacity of the reservoir. The expected economic and social benefits of the dam will be lower than expected at the planning stage because of the rapidly silt up sedimentation in the water body. The water resources development plan cannot be successful unless the upland soil erosion and reservoir sedimentation are prevented and controlled.

The above problems could be mitigated if the factors generating transportation and deposition are known and the prediction model can be developed. Most of the sediment deposition in the reservoir is generated by surface erosion at the upstream of the reservoir. It's amount and transportation depends on the degree of on-site erosion, which is the consequence of rainfall energy and land use changes. Environmental radiotracers which use natural and artificial radionuclides, for instances, ^{210}Pb, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{7}Be have been used to identify and model important particle transport processes in diverse systems including great lake, small water bodies, wetlands and coastal marine environments. Rates of particle deposition and/or transport often can be determined using particle-associated radionuclides because of their built-in clock. These radiotracers have been utilized for dating purpose on time scales spreading from some years to several decades (Oldsfield and Appleby, 1984; Wasson et al., 1987; Olley et al., 2001; Bonotto and Lima, 2006)

The principles of ^{210}Pb dating were extensively outlined by Appleby and Oldsfield (1992). The isotope ^{210}Pb occurs as part of the radioactive decay chain of ^{238}U, which presents in small quantities in the materials of the Earth's crust. ^{238}U decays through a series of non-volatile intermediates to ^{226}Ra, a solid with a half-life of 1622 years, which decays to ^{222}Rn, an inert gas with a half-life of 3.825 days.^{222}Rn decays via a series of short-lived daughters to ^{210}Pb, a solid with a half-life of 22.26 years. The lead becomes attached to the aerosols and reached the Earth's surface either by dry fallout or by being washed out of the atmosphere in precipitation. The aerosols ^{210}Pb which settles into lake waters is absorbed by suspended sediment and subsequently incorporated in the lake sediment and is referred to as unsupported or excess ^{210}Pb or in other words; it is not in equilibrium with its parent ^{226}Ra. ^{210}Pb is also formed in situ from the decay of ^{226}Ra eroded into the basin from the catchment or the decay of ^{238}U within rocks, soils minerals and sediments. The activities of this supported ^{210}Pb thus will not decreases with time resulted from continuous supply of ^{210}Pb from uranium and its daughters. While as the unsupported ^{210}Pb radioactivity in the sediments decreases by a factor of 2 every 22.26 years half-life. The rate of change of unsupported ^{210}Pb activity down a sequence may thus be used to establish the sedimentation rate.

Lam Phra Phloeng dam (Fig.1) is one of the most seriously affected by soil erosion related sedimentation dam in Thailand. Deforestation in the upper land area has reduced the forest area from 531 km^2 in 1974 to 160.25 km^2 in 1985 or about 70% reduction within 11 years. These have led to increase sediment load in rivers draining into the dam. The dominant crops in the upper catchment are sugar-cane and cassava. After the crop has been harvested the land is tilled and becomes sensitive to sheet erosion. As a direct result the dam has become very shallow and its storage capacity was reduced rapidly. In this study the sediment accumulation rates in Lam Phra Phloeng dam was estimated using the measurement of ^{210}Pb radioactivity profile in the sediment cores. Sediment accumulation rates were assessed using the constant initial concentration (CIC) of unsupported/excess ^{210}Pb model developed by Brugam (1978).

RESEARCH METHODOLGY

General features of the study area

Lam Phra Phloeng dam (Fig. 1) is located in Nakhon Ratchasima Province, northeastern Thailand between the latitude of 14° 30′- 14° 36′N and longtitude of 101° 47′- 101° 50′E. The dam was constructed in 1963 and started operation in 1967. It is located at the upper part of Lam Phra Phloeng River in a small catchment area of 820 km^{2,} which includes 10.78 km^2 as the water reservoir and 809.3 km^2 as the catchment. The catchment is a sub-basin of Moon river basin, which mostly occupied by flood plains. The foot hills located about 300-500 mean sea level (m.s.l.). The major stream flows into the reservoir is Lam Phra Phloeng River. The river flow direction is from west to east and the length of the river is about 60 km. The average annual water inflow is 241.93 million m^3. The ecology along the west and the east of the river is still a natural forest.

Rainfall is usually concentrated in the rainy season from May to October. Average annual precipitation varies from 1,270 to 2,000 mm/yr. The average annual rainfall ranged from 925 to 1,491 and averaged 1,140 mm/yr over a period of ten years from 1990 to 2000.

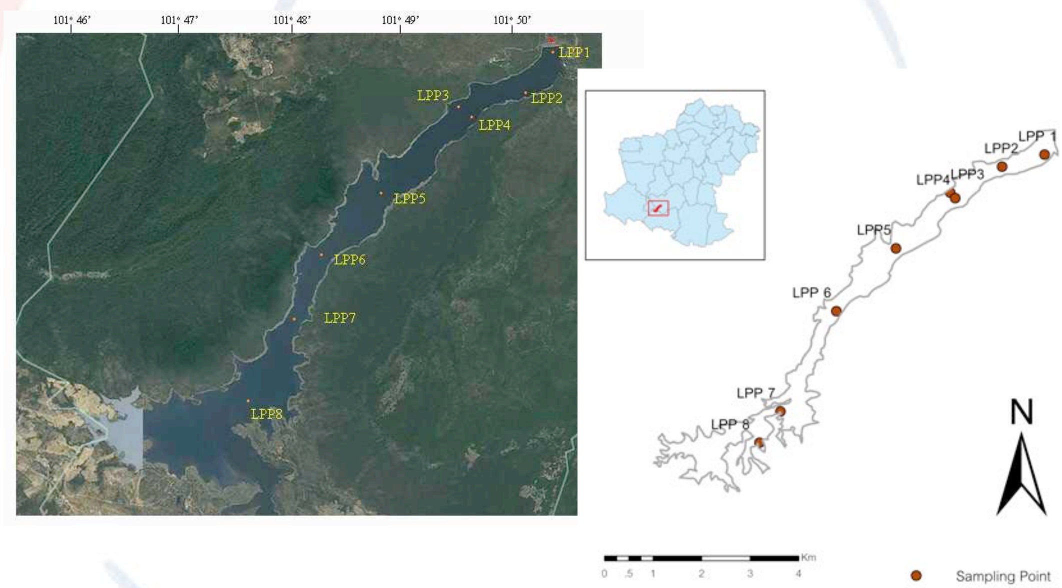


Fig. 1 A simplified map of the location of Nakhon Ratchasima Province and a portion of Lam Phra Phloeng dam, studied in this investigation. The monitoring stations are shown.

Sampling points

The study portion is in the crest dam covers the length of 11 km and the depth of 15-25 m (Fig.1). Eight sediment cores were sampled. The locations of all core sites were recorded by calibrated GPS. Horizontal position was recorded in the Universe Transverse Mercator (UTM) system based on the North American Datum of 1983 (NAD83) (Table 1). One core from each sampling site was collected using a gravity corer (Soft Cores Sediment Technologies) with a 10 kg weighing. The core is made of 75 cm acrylic tubes with inner and outer diameter of 5.4 and 6.2 cm, respectively. The sediment cores were sliced into segments of 1 cm thick by hydraulically extrusion on board ship. The sediment rim of each slice was removed and discarded to avoid contamination. The samples were put in plastic bags, stored at 4^{o}C. They were transported in an ice box to laboratory where all samples were stored at -30^{o}C until determination.

Analytical method

The water content of each section was determined after drying at 60^{o}C for the organic matter preservation and minimal loss of volatile compounds. The samples were dried for about 24 hrs or when the sample weights were constant. The dried sediments were disaggregated in a centrifugal ball mill and sieved through grain size <125 mm for removal of plants parts (roots, leaves, etc).

The particle size fraction <125 mm was analyzed based on optical laser diffraction method (Malvern Microsizer Laser Particle Sizing Analyzer). The sample to be analyzed was placed in the rotary auto-preparation station already equipped with the instrument. The samples were then diluted to the required obscuration of 10% (Pape, 1996; Buurman et al., 1997) and then automatically dispersed into the instrument. Most of the samples were analyzed twice for reproducibility of the result.

Total organic matter (TOM) of the sediment was measured by loss on ignition (LOI) (Dean, 1974). Principally about 0.5 g of dry sample was ignited in a muffle furnace for 4 hrs at 550^{o}C, cool, and reweighed. The percent weight lost is the TOM in percent.

The particle density was determined using pycnometry (Ultrapycnometer 1000, Quantachrome) (Huang et al., 1995). Helium and nitrogen gas used were of 99.99% purity. The sediment bulk density was determined based on oven-dry and weight basis. The porosity was calculated based on particle density and bulk density data.

Mineralogy was determined using X-ray diffractometer (D8 ADVANCE, Bruker). About 50 g of sediment was grounded in agate mortar and irradiated in $CuK_{\alpha 1}$ (1.54 Å for Cu) radiation. The lattice parameters and atomic position were analyzed using FULL PROF SUITE-2000 software. The X-ray tube was operated at 30 kV, 25 mA and the sample was continuously scanned in the 2θ ranged of 20^{o}-80^{o} with scanning speed of 0.02 degree per second. The X-ray diffraction data were then analyzed by comparison data with the Joint Committee on Powder Diffraction Standards (JCPDS) database.

^{210}Pb activities were determined following a modification of the procedure of Robbins and Edgington (1975) and Carpenter et al. (1981, 1982). Sample digestion involved acid treatment of dried 2-3 g sediment samples spiked with a ^{209}Po tracer for chemical yield measurement. In the wet digestion, conc. HNO_3, $HClO_4$, and HCl in different proportion were employed sequentially. The final wet-digestion step was the dissolution of the residue in 0.3M HCl, followed by spontaneous plating on a silver disc. The ascorbic acid was added to prevent the metal iron from deposition on silver disc by reduction of Fe^{+3} to Fe^{+2}. ^{210}Po and ^{209}Po activity were finally recorded by high resolution alpha spectrometry system using 450 mm^2 surface barrier silicon detectors for a minimum of 24 hrs or the total count of the main peak was up to 1000 counts. This means that the counting error determined was less than 3%. The procedure was standardized and calibrated using the IAEA reference material, IAEA-SRM 300 and IAEA-SRM 368. Replicate analysis of the sample confirmed good agreement of ^{210}Pb isotope activities with certified value (% relative accuracy ~ 107.19) which is in the acceptable range (%RPD < 10).

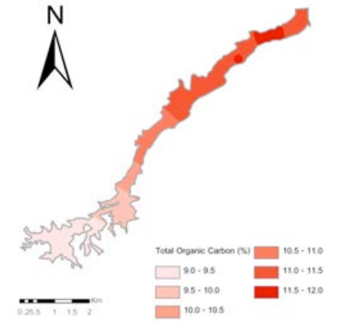
To obtain information about the parent-supported (in-situ produced) ^{210}Pb, measurements of ^{226}Ra were performed on the same homogeneous portions of dried samples from each core used for ^{210}Po analysis. Aliquots of about 2 g were submitted to gamma ray spectrometry in a well type germanium detector (GWL-120230 ORTEC Instrument). Samples were put in a glass ampoule (10mm×30mm), sealed, weighed and stored for 3 weeks waiting for ^{222}Rn to reach secular equilibrium with ^{226}Ra. The gamma spectrometer was calibrated for energy and efficiency through radionuclides (^{133}Ba, ^{152}Eu, ^{137}Cs and ^{60}Co) in the same geometry. The procedure was standardized and calibrated using the IAEA reference materials, IAEA-SRM-326 and IAEA-SRM-327.

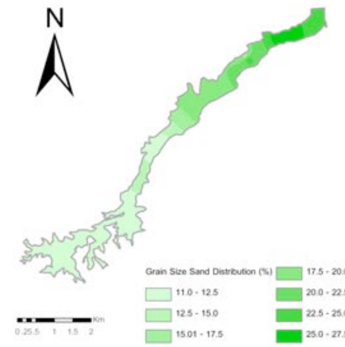
RESULTS AND DISCUSSION

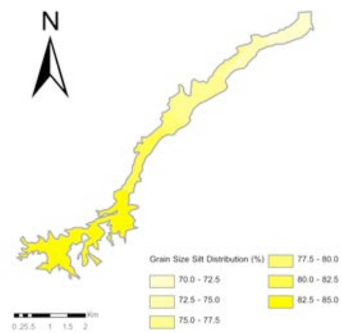
Table 1 reports the results obtained for all sediment analyzed. Physical properties such as the bulk density, porosity and organic matter, of soils and sediments influence their specific surface (area per mass, expressed in m^2/g), as 1% of organic matter in porous matrices may cause increase of the specific surface of about 7 m^2 (Kiehl, 1977 referred in Sabaris and Bonotto, 2011). Therefore, it is important to analyze such physical properties in order to evaluate their contributing to the adsorption of radionuclides here analyzed. The analyses revealed the sediments were mostly silt (60-94%), sand (up to 30%) and finally clay (2-8%). The moisture contents ranged from 33 to 75%, organic matters ranged from 7.12-13.53%, porosities ranged from 0.51-0.90, bulk densities ranged from 0.25-0.74 g/cm3, and particle densities ranged from 2.96-3.02 g/cm^3. Fig.2 shows areal distributions of organic matters, sand, silt, and clay and mass and linear accumulation rates of sediment in Lam Phra Phloeng dam,

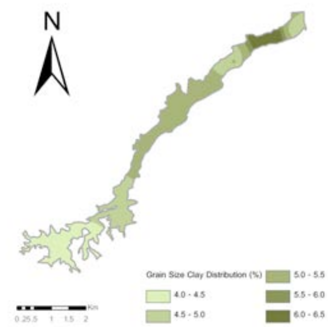
Table 1 Location, core length, particle density, porosity, surface mixed layer (SML), supported 210Pb, unsupported 210Pb activity and sedimentation rate of sediment cores of Lam Phra Phloeng Dam

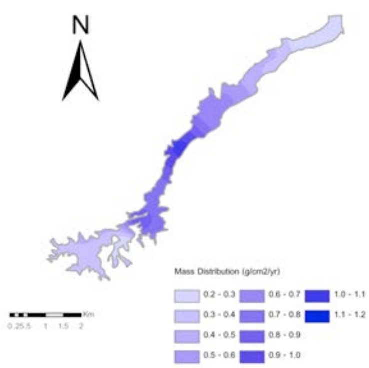
Description	Site of cores							
	LPP1	LPP2	LPP3	LPP4	LPP5	LPP6	LPP7	LPP8
Location (UTM)	806596E 1615252N	805720E 1615002N	804651E 1614465N	804755E 1614352N	803532E 1613312N	802303E 1612011N	801151E 1609948N	800719E 1609300N
Core length (cm)	36	31	43	50	47	51	24	15
Particle density	3.01	3.01	2.96	3.02	3.01	2.96	3.01	2.96
porosity	0.82-0.90	0.61-0.90	0.70-0.90	0.75-0.88	0.72-0.90	0.71-0.89	0.64-0.89	0.51-0.72
Surface Mixed Layer	0	5	7	7	14	14	4	6
Supported 210Pb	7.02±1.16	9.10±1.38	5.05±0.67	5.23±0.71	4.96±0.76	8.04±1.05	7.01±0.94	7.23±0.95
Unsupported 210Pb activity	59.67±11.8 6 to	59.29+13.3 5 to 33.83+7.97	61.98+12.8 1 to 26.64+6.34	66.12+13.26t o 26.83+6.62	51.62+10.19t o 27.00+5.69	55.27+11.90t o 28.92+7.34	57.15+11.9 6 to 21.15+5.11	36.37+8.68t o 15.79+4.49
Sedimentatio n rate (CIC) (g/cm2/yr)	0.26+0.03	0.24+0.02	0.50+0.09	0.33+0.03	0.61+0.15 and 0.62+0.14	1.02+0.20	0.87+0.17	0.21+0.06


N
Total Organic Carbon (%)
9.0 - 9.5
9.5 - 10.0
10.0 - 10.5
10.5 - 11.0
11.0 - 11.5
11.5 - 12.0
0.25.5 1 1.5 2
Km


N
Grain Size Sand Distribution (%)
11.0 - 12.5
12.5 - 15.0
15.01 - 17.5
17.5 - 20.0
20.0 - 22.5
22.5 - 25.0
25.0 - 27.5
0.25.5 1 1.5 2
Km


N
Grain Size Silt Distribution (%)
70.0 - 72.5
72.5 - 75.0
75.0 - 77.5
77.5 - 80.0
80.0 - 82.5
82.5 - 85.0
0.25.5 1 1.5 2
Km


N
Grain Size Clay Distribution (%)
4.0 - 4.5
4.5 - 5.0
5.0 - 5.5
5.5 - 6.0
6.0 - 6.5
0.25.5 1 1.5 2
Km


N
Mass Distribution (g/cm2/yr)
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
1.0 - 1.1
1.1 - 1.2
0.25.5 1 1.5 2
Km

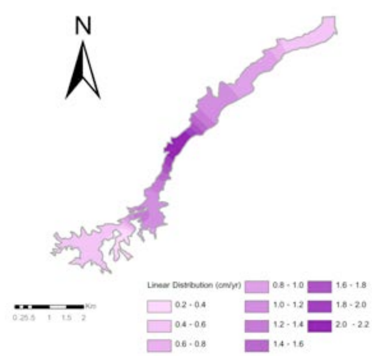

N
Linear Distribution (cm/yr)
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
1.0 - 1.2
1.2 - 1.4
1.4 - 1.6
1.6 - 1.8
1.8 - 2.0
2.0 - 2.2
0.25.5 1 1.5 2
Km

Fig. 2 Areal distribution of total organic carbon, sand, silt, and clay, mass and linear accumulation on a simplified map of the Lam Phra Phloeng Dam, Nakhon Ratchasima Province, Thailand. The highest mass accumulation rate corresponding to 1.02 g/cm^2/yr was found at station LPP6, where the lowest accumulation rate corresponding to 0.21 g/cm^2/yr was found at station LPP8.

XRD results showed the mineralogy included illite ($KAl_2Si_3AlO_{10}(OH)_2$), kaolinite ($Al_2SiO_2O_5(OH)$), covellite (CuS) and quartz (SiO_2) in all sample cores except LPP8 which its main mineralogy composed of just covellite and quartz. The composition of the sediment reflects the constituents of the rock in the study area that are dominated by minerals containing mainly Si and Al and minor amounts of K, S and Cu.

The total ^{210}Pb activities ranged from 23.02$\pm$4.49 to 71.35$\pm$13.26 Bq/kg. The supported ^{210}Pb analyzed by gamma-spectrometry ranged from 4.96$\pm$0.76 to 9.10$\pm$1.38 Bq/kg.

The sedimentation rate was evaluated by the CIC (Constant Initial Concentration) of unsupported ^{210}Pb model (Appleby and Oldsfield, 1978). Whereas the ln(unsupported ^{210}Pb) was plotted against the cumulative mass per unit area, the resulting ^{210}Pb profile will be linear with slope is $-\lambda_{210}/f$. λ_{210} is the radioactive constant for ^{210}Pb (0.0311 yr^{-1}). The sediment mass flux or deposition rate, f was determined from the mean slope of the profile using the least-square-fit procedure (Baskaran and Nandu, 1995).

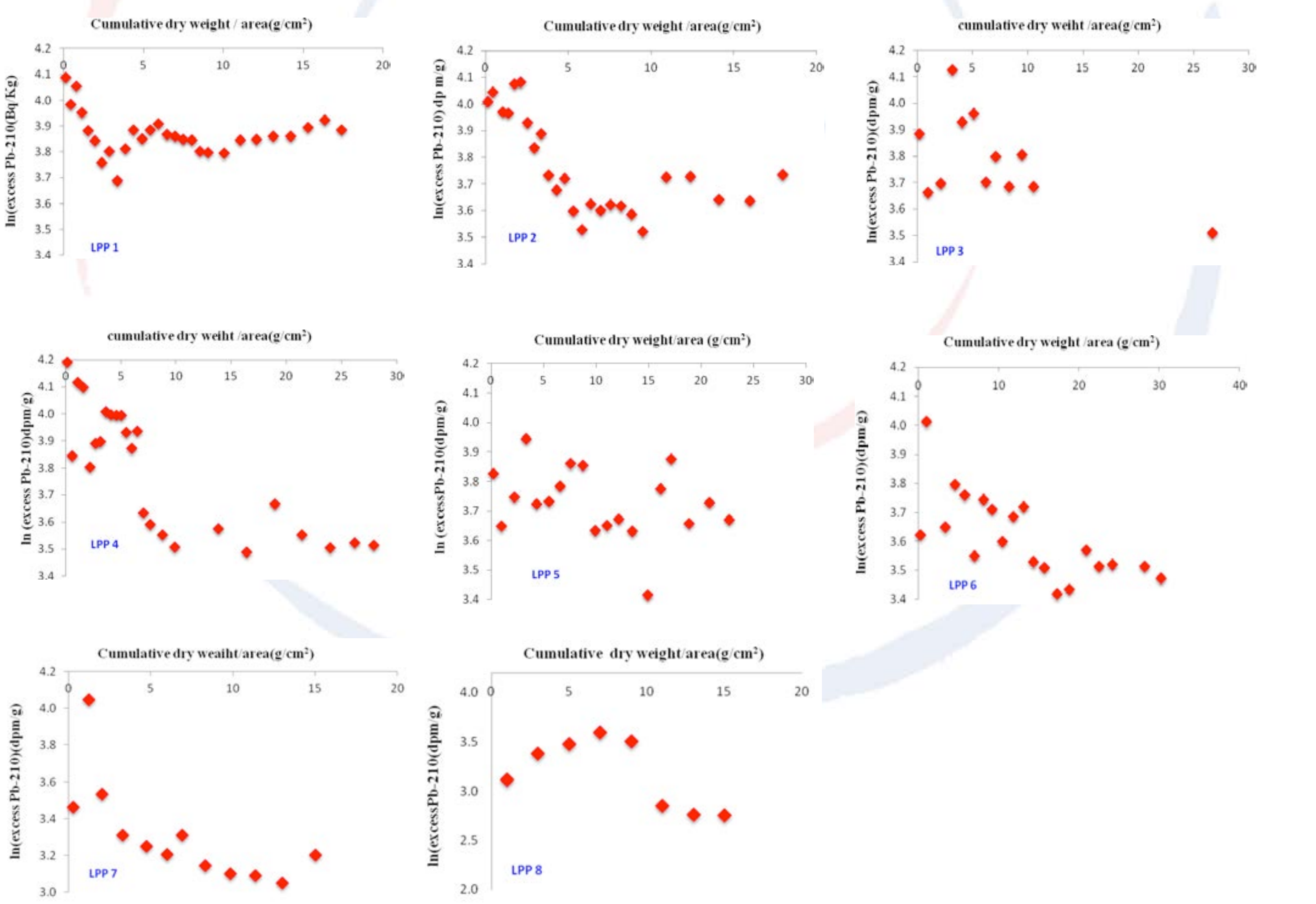


Fig. 3 Unsupported ^{210}Pb activities vs. cumulative dry mass relationships in the sediment cores collected at Lam Phra Phloeng crest dam basin, Nakhon Ratchasima Province, Thailand. The sediment mass accumulation rates allowed estimated linear

sedimentation rates; LPP1-0.55 cm/yr, LPP2-0.41 cm/yr, LPP3-0.79 cm/yr, LPP4-0.92 cm/yr, LPP5-1.03 cm/yr, LPP6-2.20 cm/yr, LPP7-1.27 cm/yr, LPP8-0.19 cm/yr.

In this study, the sediment mass fluxes were obtained by plotting the linear regression of natural log of unsupported ^{210}Pb activities against the cumulative dry weight per unit area for all individual cores (Fig. 3). The goodness of fit for all ages in determining the sedimentation rate was obtained from a least square regression lines. The least square best fit yield correlation coefficients statistically acceptable at $r^2 > 0.80$. The apparent sediment flux or deposition rate in Lam Phra Phloeng dam ranged from 0.21 to 1.02 g/cm^2/yr.

The deposition time (in years) may be calculated by dividing the cumulative dry weight per unit area by the sediment mass accumulation rate. The average linear sedimentation rate (in cm/yr) can be evaluated by the division of the total thickness of the sediment cores by the deposition time at the deepest layer. The values estimated are: LPP1-0.55 cm/yr, LPP2-0.41 cm/yr, LPP3-0.79 cm/yr, LPP4-0.92 cm/yr, LPP5-1.03 cm/yr, LPP6-2.20 cm/yr, LPP7-1.27 cm/yr, and LPP8-0.19 cm/yr. They are relatively high when compare to our previous investigation at Bang Pakong and Chantaburi river estuary (0.46-0.69 cm/yr) (Cheevaporn and Mokkongpai, 1996), Lamtan and Sichang-Sriracha channel (0.14-0.21 cm/yr) (Srisuksawad and Rungsupa, 2002) and Pattani Bay (0.54-0.82 cm/yr) (Kaewtubtim, 2008) but comparable to 0.16-1.92 mm/yr in Atibaia River basin, Sao Paulo State, Brazil (Sabaris and Bonotto, 2011) and 0.87-3.10 mm/yr in Cordeax reservoir, Sydney, Australia (Simms et al., 2008).

The major areas of sediment accumulating were LPP6 and LPP7 or about 3-5 km. far from the upper end of the dam. The high velocity water stream carried the sediments from the upper catchment into the dam. When it entered into the dam its velocity decreased gradually to the steady state and coarse sediment deposited. The water stream continued to lose its velocity and transport finer particles slowly and finally deposited it near the crest of the dam.

Table 2 Sediment accumulation per year calculated for sub-area of reservoir

Description	Area (X 10^{10} cm^2)	Sedimentation rate (g/cm^2/yr)	Average Bulk Density (g/cm^3)	Sediment accumulation (X10^4 tons/yr)	Percent of total
LPP1	0.5	0.26	0.37	0.130	2.367
LPP2	0.8	0.24	0.42	0.192	3.497
LPP3	0.55	0.50	0.44	0.275	5.008
LPP4	0.57	0.33	0.41	0.188	3.424
LPP5	2.3	0.61	0.43	1.403	25.555
LPP6	1.3	1.02	0.44	1.326	24.149
LPP7	1.5	0.87	0.48	1.305	23.766
LPP8	3.2	0.21	0.65	0.672	12.238
Total	10.72			5.491	100

Lam Phra Phloeng dam has its water receiver area of 1.072×10^{12} cm^2, if divided into 8 sub-areas according to the sampling point. The sediment deposition in each area can be calculated and showed in Table 2.

The total sediment deposition in the dam is 5.491×10^4 tons/year compatible to rate of erosion of 2.27 mm/year correlated with the result from previous investigation done by the Royal Irrigation Department. More than 80% of sediment was deposited in the area between LPP5-LPP8 and more than 50% was deposited in the area between LPP5-LPP6. The study results will be benefit for efficient dredging planning of the dam.

CONCLUSIONS

Eight sediment profiles were sampled at the Lam Phra Phloeng crest dam, in order to determine sedimentation rates by the ^{210}Pb method. Aliquots were separated from sections of each core for determining the mineralogy or crystal structure (by XRD), total organic matter (by ignition loss), particle size (by optical diffractometry method) and radionuclides. Alpha spectrometry was used to determine the ^{210}Pb activities (total ^{210}Pb) in each segment from the sediment profiles. The supported ^{210}Pb was evaluated by the equivalent uranium (^{226}Ra) through gamma spectrometry, whereas the excess ^{210}Pb was determined by the difference between total ^{210}Pb and supported ^{210}Pb activities. The results found in the sediment profiles revealed the sediments were mostly silt (60-94%), sand (up to 30%) and clay (2-8%). The moisture contents ranged from 33 to 75%, organic matters ranged from 7.12 to 13.53%, porosities ranged from 0.51 to 0.90, bulk densities ranged from 0.25 to 0.74 g/cm^3, and particle densities ranged from 2.96 to 3.02 g/cm^3. XRD results showed in all sample cores, except LPP8, the main mineralogy composed of illite, kaolinite, covellite and quartz whereas for LPP8 the main mineralogy was only covellite and quartz. This reflects Si and Al are the main constituents of the rock in the study area whereas K, S, and Cu are the minors. The sedimentation rates ranged from 0.21 to 1.02 mg/cm^2/yr (0.19 to 2.20cm/yr); the highest values were found within 3-5 km. radius from the upper end of the dam, whereas the lowest one were at the upper most and lower end or at the crest of the dam.

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