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Educational and Research Programs to Develop Sustainable Watershed Management[1]

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The educational objective of the study program for watershed management (SPWM) at Bogor Agricultural University (IPB) is to develop professionalism and deepen graduates' understanding of basic, applied and advanced sciences so that they may: a) identify watershed characteristics and functional linkages of the components, b) identify problems in watershed systems, c) formulate integrated watershed management plans to increase productivity, stability and sustainabilty of natural resources, and d) carry out both interdisciplinary and highly specialized research (IPB, 2008).

The main competencies required of graduates of the master of science program are: (a) capability to manage watersheds through problem identification and quantification of land management issues in watershed areas (i.e., floods, droughts, erosion and sedimentation, reduction of land productivity), (b) capability to identify and measure the effect of watershed management strategies and techniques designed to overcome problems stemming from the misuse of land resources, and (c) capability to design sustainable watershed managment plans. For doctorate programs, the target competency is the ability to identify and answer gaps in scientific knowledge so as to improve the planning and application of strategic watershed management for maintaining sustainable watershed resources.

Integrated watershed management and sustainable agriculture are explicitly described in the curriculum of SPWM through subjects that include: soil and water conservation; analysis of hydrological systems; land use planning; sustainable agricultural systems; water resource planning; watershed management; and watershed management technology, strategy, and policy.

The majority of research efforts have been directed at maintaining and increasing watershed functions to support the dynamics of life, incorporating ecological, economic, and social dimensions. Projects have been designed to: (a) select soil and water conservation technologies (site specific), (b) explore several indigenous integrated conservation farming systems, (c) study land use change, (d) design watershed management plans, (e) minimize flooding (magnitude and frequency), (f) increase water availability (spatially and temporally), (g) estimate the effects of floods and flood mitigation, (h) increase and develop institutional roles in watershed management, and (i) develop and apply hydrological and erosion models. Sustainability indicators examined in these research programs have included enhanced farmer outcomes (economic viability), increased adoption of technology by farmers using locally available resources (technologically appropriate), and no significant degradation of natural resources (ecologically friendly).

Key words: education, erosion model, research, sustainable agriculture, watershed management

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[1] A case study at Study Program of Watershed Management, IPB

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Introduction

Most of the watersheds in Indonesia have been classified as being seriously threatened by land degradation (Arsyad, 2000). Watershed degradation has commonly resulted from forest conversion and agricultural practices that lack adequate application of soil and water conservation technologies. Forest conversion to agricultural land followed by subsequent conversion to residential and more intensive urban uses has been the primary process leading to a decline in the sustainability of the hydrologic, ecological, and economic functions of watersheds.

The study program of watershed management (SPWM) is a graduate study program at Bogor Agricultural University (*Institut Pertanian Bogor*; IPB). The aim of the SPWM is to develop professionals with a deep understanding of the basic, applied and advanced sciences who can: (a) identify watershed characteristics and functional linkages of the components, (b) identify problems in watershed systems, and (c) formulate integrated watershed management plans to increase productivity, stability, and sustainabilty of natural resources so as to fulfil human requirements both now and into the future. These objectives are pursued through the teaching curricula and research activities dealing with various aspects of SPWM.

The most serious problems of watershed management in Indonesia are primarily related to the agricultural sector. Agricultural activities on steep slopes in upper catchments cause increased surface runoff and soil erosion during the rainy season. Concentration of surface runoff in lowland areas causes floods in settled areas, and poor retention of water received in the rainy season leads to water scarcity in the dry season (increased distribution and duration of drought). Overland flow and soil erosion transport soil particles, organic matter, and nutrients away from agricultural land, leading to a decline in soil fertility. This reduction in soil fertility will cause a direct decrease in agricultural productivity, and in turn this will cause further degradation, especially of marginal soils. Therefore, improvements to the sustainability of agricultural practices will greatly help to conserve watershed functions and in turn will contribute to the sustainability of watershed management. This paper describes the curricula and research activities in SPWM at IPB to develop sustainable watershed management (sustainability of agriculture).

Educational Objectives and Curricula

Educational Objectives of the Study Program of Watershed Management

The educational objective of SPWM at IPB is to develop professionalism and deepen graduates' understanding of basic, applied and advanced sciences so that they may: a) identify watershed characteristics and functional linkages of the components, b) identify problems in watershed systems, c) formulate integrated watershed management plans to increase productivity, stability and sustainabilty of natural resources, and d) carry out both interdisciplinary and highly specialized research (IPB, 2008).

The main competencies required of graduates of the master of science program are: (a) capability to manage watersheds through problem identification and quantification of land management issues in watershed areas (i.e., floods, droughts, erosion and sedimentation, reduction of land productivity), (b) capability to identify and measure the effect of watershed management strategies and techniques designed to overcome problems stemming from the misuse of land resources, and (c) capability to design sustainable watershed managment plans. For doctorate programs, the target competency is the ability to identify and answer gaps in scientific knowledge so as to improve the planning and application of strategic watershed management for maintaining sustainable watershed resources.

Curricula of the Study Program of Watershed Management

Integrated watershed management and sustainable agriculture are explicitly taught in the SPWM both in master of science (MS) and doctorate (PhD) programs. In MS program the subjects are include: watershed management, soil and water conservation, analysis of hydrological systems, and land use planning. While watershed management technology, watershed management strategy, water resources planning, watershed management policy, and sustainable agriculture systems are compulsory subjects in the PhD program (Table 1).

Table 1. Subjects in study program for watershed management (SPWM) (IPB, 2008)

Subject Code	Subject	SCU[1]
	Master of science program	
	Core subjects of the graduate program (6 SCU)	
PPS 500	English	3
TSL 500	Geostatistics	3
	Core subjects of SPWM (25 SCU)	
TSL 631	Watershed management	3(2-3)[2]
GFM 641	Hydrology systems analysis	3(2-3)
TSL 504 TSL 601	Regional geobiophysics or Land use planning	3(3-0)
TSL 531	Soil and water conservation	3
TEP 625	Technical hydrology	3(2-3)
TSL 506 TSL 502	Research methodology for regional planning or Research methodology for soil and land studies	2(2-0)
PPS 601	Colloquium of master of science program	1
PPS 690	Seminar of master of science program	1
PPS 699	Research and master of science thesis	6
	Minor or supporting subjects (9 SCU) Students with supporting subjects choose a minimum of 9 SCU subjects from the other majors with a first digit in the subject code of 5 or 6.	
	Total SCU	**37**
	Doctorate program	
	Core subjects of the graduate program (2 SCU)	
PPS 702	Introduction to science philosophy	2
	Core subjects of WMSP (32 SCU)	
TSL 632	Watershed management technology	3(3-0)
TSL 731	Watershed management strategy	3(3-0)
TSL 732	Sediment transportation	3
TEP 628	Water resources system planning	2
TSL 733	Watershed management policy	3(3-0)
TSL 602	Sustainable agricultural systems	3
TSL 700	Special topic on watershed management	3
PPS 701	Colloquium of PhD program	1
PPS 790	Seminar of PhD program	1
PPS 799	Research and PhD dissertation	12
	Minor or supporting subjects (9 SCU) Students with supporting subjects choose a minimum of 9 SCU subjects from the other majors with a first digit in the subject code of 6 or 7.	
	Total SCU	**43**

[1] SCU: Semester Credit Unit

[2] 3(2-3): the subject has 3 SCU consist of 2 hours in class room (2 SCU) and 3 hours in a field or practical work (1 SCU)

Master Science Program

The watershed management subject are focuses on several topics related to watershed management such as rainfall, interception, infiltration, surface runoff, soil erosion, floods, unit hydrograph, infiltration and surface runoff models, hydrology and flood models, and watershed management model. Application of soil and water management principles to analyze watershed characteristics (especially on agricultural watershed), analyze and develop flood and sediment mitigation measures, analyze utilization plans and the sustainability of soil and water resources, and analyze and develop models for watershed management plans.

The soil and water conservation subject are study of soil erosion processes, soil degradation and its consequences, soil and water conservation principles, hydrology, soil and water conservation methods, soil cover crops, plant rotation and agroforestry, land capability classification, and the prediction and evaluation of soil erosion.

The analysis of hydrological systems subject are introduces and studies hydrological principles, theories and application of a systems approach to hydrology and water resources; surface runoff estimation and hydrograph analysis; geographical information systems and hydrologic modeling (distributed hydrologic modeling); and the current status and development of hydrologic models, especially for small watersheds.

The land use planning subject are discuss planning theories, process and models; sustainability principles; definition of land use and land use planning; land use planning for sustainable agriculture development; land use planning for a rural, urban, and transmigration areas; and contemplation of land use planning in Indonesia and the other countries.

Doctorate Program

Watershed management technology, strategy and policy are compulsory subjects focusing to maintain sustainability of watershed functions both ecologically and economically. Watershed management technology are discuss traditionally and sophisticated technology of watershed management, examples of successful and unsuccessful application of watershed technology in the field which accompanied with socio-economic analyses, examples field experience in developing/undeveloped countries, best management practices (BMP) in watershed management, design of hydrology parameter of BMP, computer model to analyze BMP, and key parameter of watershed management in agro-climatic zones.

The watershed management strategy are discuss perspectives, principles and methods of integrated watershed management, climate and hydrology considerations on watershed management, agro-ecological zone, spatial plan on watershed management, land use change and evaluation, application of hydrology model, global climate change issues in watershed management and it's consequence on strategy of watershed management. While watershed management policy are focuses on institution of watershed management, economic valuation, sustainable land use plan, logical frame work, application of logical frame work on watershed and natural resources management, conflict and conflict mediation, law and regulation of watershed management, and case study of watershed management in the world.

The water resources planning subject are discuss definition and principles of water resources system plan, identification of water management system, surface and ground water resources, sustainability of water utilization, watershed management and water quality, social value and environmental impact of water utilization, law and regulation of water resources. The sustainable agriculture subject are focuses on several topics related to sustainable agriculture both in biophysics and socio-economics aspects, integrated farming system, sustainability principles, land use planning to sustainable agriculture, policy analyses on agricultural sector, and economic valuation.

Research Activities

Graduate Research at Bogor Agricultural University

Even though no dissertations at IPB have explicitly involved a comprehensive treatment of sustainable agriculture (Perpustakaan Pusat IPB, 2008), the majority of dissertation research projects over the last 10 years were conducted to resolve problems required to increase agricultural productivity and farmer prosperity, to decrease degradation of natural resources and develop environmentally sound practices, and to develop stakehold-

Research over the last 10 years can be classified into the fields of biotechnology, genetics, and biochemistry (16.0%); agronomy, soil fertility and fertilizers, plant breeding, peat soil, integrated agriculture, and precision farming (12.5%); marine and fisheries issues (9.9%); forestry, forest conservation, forest productivity, flora and fauna, agroforestry, and community forestry (8.0%); agribusiness and agro-industries (8.0%); post-harvest activities, food technology, nutrition, and household economics (7.2%); policy analysis (6.7%); livestock (5.6%), land use planning (3.5%); and miscellaneous others (Table 2).

In biology, research has primarily focused on the selection of more productive plants and animals, increased hardiness of plants (resistance to stresses

Table 2. Dissertation topics of the graduate program at IPB (1998–2008)

Research Fields	Important key words	Quantity	
		Number	%
Forestry (conservation forest, forest yield, native flora and fauna, agroforestry, community forestry)	Forest margins, mangrove-shrimps, rubber, coffee, rattan, national park, environmental cost/value, methane mitigation, pulp and paper industries, wood supply and demand, adaptation and domestication, habitat, conservation, fugitive area, Java rhino, energy balance, ecotourism, and seed bank	91	8.0
Biology (biotechnology, genetics, biochemistry)	Fungi, mycorrhizae, bioremediation, genetics biodiversity, genetic characteristics, gene expression, gene integration, gene construction, DNA markers, and virulency	182	16.0
Agronomy (soil fertility and fertilizer, rice soil, integrated farming, plant breeding, oil palm production, precision farming)	Nutrient availability and characteristics, nutrient optimization, rice, peat soil, acid sulfate soil, mycorrhizae, rhizobia, seed germination, zinc and cocoa, water and solar radiation stress (shelter), aluminum stress, sustainability of upland farming, organic matter, plant livestock integration, water stress, earthworms, and land suitability	143	12.5
Social economy (agribusiness and agroindustry)	Poverty, welfare, home industry, rice, farmer, farm worker, coconut, soybean, milk cow	91	8.0
Plant protection	Mosaic virus, *Ganoderma*, oil palm, *E. coli*, termite control, herbicide (glyphosate)	35	3.1
Livestock	Food materials, chicken, meat production, energy and protein requirement, yield optimization of calves and milk	64	5.6
Marine and fishery	Milkfish, shrimp, fishery harbor, abundance analysis, food materials, nutrient, oceanographic characteristics, marine protection area, utilization of small islands, safety of ship operation	113	9.9
Post-harvest activities, food and nutrient technologies, and house hold	Oil palm extraction, rubber coagulation using ultrasonic method, pineapple industries, fruit storage length, family health, child nutrition, pregnancy, and child profile and IQ.	82	7.2
Veterinary science	Veterinary science	28	2.5
Hydrology and irrigation	Climate, flood, water quality, irrigation systems and models, drinking water, regional water management	20	1.8
Land use planning	Optimization, layout design, land suitability, land capability, forest fires, coastal area plans	40	3.5

Table 2. **(Continuation)** Dissertation topics of the graduate program at IPB (1998–2008)

Research Fields	Important key words	Quantity	
		Number	%
Policy analysis	Decentralization, fiscal policy, trade liberalization, foreign trade, banking patterns, budget deficit, water pricing	76	6.7
Phytopharmacy	Ginger, *Andrographis paniculata*, hepaprotector, diabetes, cancer	16	1.4
Institution and community empowerment	Analysis of institutional systems, cooperatives, banking system for marine communities, mangrove, marginal farmers, marginal land, small businesses, shifting cultivation	28	2.5
Pollution (erosion and heavy metals)	Reservoirs, rivers, acid rain, carbon emissions, mercury, chromium, biochemical effects on fish, coastal areas of small islands, industrial pollution	23	2.0
Waste management	Water plants, phytoremediation, bioreactors, waste from gold mining, oil palms, waste management technology, hydro-isotopes, renewable energy, earthworms	25	2.2
Land rehabilitation	*Imperata cylindrica*, fungi mycorrhizae arbuscular, mine acids, agroforestry	12	1.1
Environment	Impact analyses, valuation of environmental degradation, sugar factory, externalities, community roles, environmental valuation.	21	1.8
Regional development	City-village relationships, village revitalization, poverty, regional economy, transmigration, poverty and regional economy, agro-estates, corruption, ecotourism, and village-city transformation.	31	2.7
Urban forests	Urban forest, green open space	7	0.6
Others	Soil mechanics, radiology, neural networks	13	1.1
	Total	**1141**	**100**

related to water, aluminum, and shelter), and increased plant and animal productivity using genetic engineering. Research to overcome environmental pollution using bioremediation technology has also been conducted. In agronomy, research has focused on increasing seed germination and production and plant productivity, nutrient characteristics, nutrient availability and optimization, land suitability, land improvement, upland farming, integrated farming, organic farming, plant residue management and composting, earthworms, and peaty and acid sulfate soils. Research on marine and fisheries issues have focused on overcoming various problems in aquaculture, especially concerning shrimp and milkfish culture, and nutrients; abundance analysis; conservation of marine protection areas; geographical information systems; oceanographic characteristics; utilization of small islands; and safety analysis of shipping operations.

Research on environmental issues has appeared in relation to several aspects of forestry, such as mangrove conservation, national parks, agroforestry (rubber and coffee), methane emission and mitigation from wetland area, adaptation and domestication of wild plants and animals, habitat conservation, and ecotourism.

Research within the Study Program of Watershed Management

The main research projects carried out in the SPWM program have focused on resolving various problems related to watershed management. The most common issues have included: sustainable agriculture, conservation farming, integrated farm-

ing, surface runoff, soil erosion, sedimentation and pollution, flood and drought, flood mitigation, hydrologic and soil erosion models, land use conversion and land use planning, and sustainable development.

Due to the close relationship between sustainable agriculture and sustainable watershed management, the majority of the research projects have been directed at both maintaining and increasing watershed functions to support life dynamics, incorporating ecological, economic, and social dimensions. The research was designed to: (a) select soil and water conservation technologies (site specific), (b) explore several indigenous integrated conservation farming system, (c) study land use change, (d) design watershed management plans, (e) minimize flooding (magnitude and frequency), (f) increase water availability (spatially and temporally), (g) estimate the effects of floods and flood mitigation, (h) increase and develop institutional roles in watershed management, and (i) to develop and apply hydrological and erosion models. The main erosion models that have been adopted in research projects include the Universal Soil Loss Equation (Wischmeier and Smith, 1978), Agriculture Nonpoint Source Model (Young *et al.,* 1994), Areal Nonpoint Source Watershed Environment Response Simulation (Beasley and Huggins, 1982), Flood Hydrograph Package from Hydrologic Engineering Center (HEC, 1998) and Soil and Water Assessment Tools (Neitsch *et al.,* 2001).

Sustainability indicators examined in these research programs have included enhanced farmer outcomes (economically viability), increased adoption of technology by farmers using locally available resources (technologically appropriate), and no significant degradation of natural resources (ecologically friendly). "Ecologically friendly" is an important indicator of agricultural sustainability in SPWM research projects.

Example Dissertation Project

An example of one dissertation research project conducted in the SPWM of IPB has title: " Reformulation of crop and management factors in ANSWERS and the USLE to predict surface runoff and soil erosion in tropical humid areas (case study of Nopu Upper Watershed, Central Sulawesi)". The research was proposed to: a) identify the impact of rainforest conversion on surface runoff, soil erosion and nutrient loss, b) reformulate crop and management factors in ANSWERS model, c) integrate the ANSWERS and PCRaster models to simulate land use change impacts and the effects of applying different soil and water conservation techniques, and d) modify the USLE model to predict watershed soil erosion. Detail of the research is attached in Appendix 1.

Primary output of the research was: a) forest conversion into agricultural areas increased surface runoff, soil erosion and nutrient loss. Nutrient losses from agricultural areas were higher than those from natural forest even though nutrient concentrations in sediment and surface runoff from natural forest were higher; b) partial C-factor were more appropriate to use as input parameters in ANSWERS and the other event-based erosion models; c) ANSWERS model was successfully integrated to PCRaster model with additional subroutines for ridge terraces were installed; and d) reforestation of very steep land (>45%) in Nopu Upper Watershed followed by the application of ridge terraces on agricultural areas, were the best management practices to control surface runoff and soil erosion so as to ensure sustainable agriculture and sustainable watershed functions.

Conclusion

The educational and research programs in SPWM have been designed to contribute to sustainable watershed management by recognizing that sustainable agriculture is a prerequisite to achieving sustainable watershed management in Indonesia. Integrated watershed management and sustainable agriculture are explicitly covered in the curricula of SPWM.

Research projects in SPWM have been designed to: (a) select soil and water conservation technologies (site specific), (b) explore several indigenous integrated conservation farming system, (c) study land use change, (d) design watershed management plans, (e) minimize flooding (magnitude and frequency), (f) increase water availability (spatially and temporally), (g) estimate the effects of floods and flood mitigation, (h) increase and develop institutional roles in watershed management, and (i) develop and apply hydrological and erosion models.

Sustainability indicators applied in the majority of the research conducted within SPWM have focused on ecological aspects. In several research projects, the economic viability and appropriateness of a technology have also been examined.

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Appendix 1. Example Dissertation Project

Research Title

Reformulation of crop and management factors in ANSWERS and the USLE to predict surface runoff and soil erosion in tropical humid areas (case study of Nopu Upper Watershed, Central Sulawesi)

Research Objectives

- To identify the impact of rainforest conversion on surface runoff, soil erosion and nutrient loss.
- To reformulate crop and management factors in ANSWERS to increase the accuracy of predictions of surface runoff and soil erosion in tropical humid settings.
- To integrate the ANSWERS and PCRaster models to simulate land use change impacts and the effects of applying different soil and water conservation techniques.
- To modify the USLE model to predict watershed soil erosion.

Methodology

Field Research

- Location: Nopu Upper Watershed, Central Sulawesi (ca. 250 ha). Collaborative research carried out in conjunction with the STORMA (stability of rainforest margins) project.
- Rainfall measurement using automatic rainfall recorder (datalogger-based) and daily measurement of interception (throughfall and stemflow).
- Daily measurement of surface runoff and soil erosion on soil erosion plots installed in primary forest, secondary forest, open areas, maize, peanut, young cocoa, intermediate-aged cocoa, old cocoa, and intercropping between young cacao, maize, banana, and cassavas.
- Measurement of surface runoff and sediment discharge using weirs (installed by STORMA) and dataloggers at three positions in the watershed (upper, middle, and outlet).
- Measurement of land use cover (coverage) by digital camera and threshold analysis of digital images.
- Measurement of soil permeability using a Guelph permeameter.

Laboratory Analysis

- Soil chemistry (before and after research): organic matter, total nitrogen, cation exchange capacity, exchangeable base cations, available phosphorus, and available metal cations (iron, manganese, zinc, and copper).
- Surface runoff (certain samples): dissolved organic carbon, dissolved inorganic carbon, NO_3-N, total nitrogen bounding, base cations (calcium, magnesium, potassium, and sodium), and phosphorus.
- Sediment (certain samples): organic carbon, total nitrogen, available phosphorus, exchangeable base cations (base saturation), and available metal cations (iron, manganese, zinc and copper).

Development of Soil Erosion Models

- Integration of the ANSWERS model to PCRaster

- Modification of the USLE model to predict watershed soil erosion.

Model Applications

- To simulate land use change management to control surface runoff and soil erosion.
- To select the best soil and water conservation techniques to maintain and increase watershed functions and benefits.

Research Outputs

Forest Conversion Impacts

- Forest conversion into agricultural areas increased surface runoff, soil erosion and nutrient loss. Compared with natural forest, surface runoff in open areas increased by 659%. Surface runoff also increased in young cocoa (335%), medium cocoa (334%), intercropping of young cocoa and bananas (280%) and young cocoa, maize, and cassava (262%). After natural forest (31 mm), the next lowest surface runoff was produced by a system involving the rotation of maize and peanut (66 mm).
- In accordance with the results of previous research (Roose, 1986), soil erosion in open areas increased by 2365% compared with natural forest. Soil erosion also increased in the maize and peanut rotation (585.8%), young cacao (580%), intercropping of young cocoa and cassava (541%) and intercropping of young cacao, maize and cassava (537%). Erosion on shrub and bush areas (especially *Imperata cylindrica*) was lower than in all other areas except natural forest.
- Even though nutrient concentrations (C, N, P, K, Ca, Mg, K, Na) in sediment and surface runoff were higher from natural forest than from agricultural areas, total nutrient losses from agricultural areas were higher than those from natural forest. In addition, nutrient loss through surface runoff was greater than through soil erosion except for phosphorus.

Crop Management Factor (C-factor)

- Value of partial C-factor (daily C-factor) vary in accordance with canopy cover. The value was higher in early season when canopy cover relatively lower and it's increase with enhancement of canopy cover. While USLE C-factor is a single value used in USLE model in the others.
- Using a partial C-factor, the ANSWERS model performs better in predicting soil erosion than the USLE C-factor. Therefore, partial C-factors were more appropriate to use as input parameters in ANSWERS and the other event-based erosion models.

Development of a Distributed Soil Erosion Model

- ANSWERS model was successfully integrated with the PCRaster model through modification and construction of scripts in PCRaster.
- To accommodate soil and water conservation techniques commonly applied in Indonesia, subroutines for ridge terraces were installed in the model.

Simulation of Land Use Changes and Soil and Water Conservation Techniques

- The application of ridge terraces in agricultural areas (annual crops, cocoa) significantly reduces surface runoff and soil erosion. The effectiveness of ridge terraces in reducing surface runoff and soil erosion were found to decrease as rainfall increases.
- Reforestation of very steep land (>45%), followed by the application of ridge terraces on agricultural areas, were the best management practices to control surface runoff and soil erosion so as to ensure sustainable agriculture and sustainable watershed functions.