Erosion Mitigation Based on the Geographic Information System (GIS) With Agroforestry for Water Conservation Concept

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開発と地球温暖化による豪雨などの影響でインドネシアの河川流域では土壌の浸食が急速に進んでいる。土地を守るための森林再生事業も一貫性を欠く。森林保護と農業生産の持続可能な共存に向けた施策をGISのデータに基づき考察する。

Abstract

The lack condition of upper Bango watershed happened due to the average erosion rate that reaches 126.81 ton/ha/year. The gap is significantly huge compared to the tolerance threshold of 12.5 ton/ ha/ year. Actually, the management of Bango upstream is directed to the protected areas, but its development towards protected areas tend to be less effective because sustainability management also ended after the reforestation program. In addition, the land acquisition increasingly forces the function of the existence of the upstream area. Therefore, it needs a reforestation model that could empower public life, also sustainable, economically valuable and is able to maintain the environmental quality of the catchment area. Thus, the expected agroforestry planning concept can help solving the problem of protected areas in upper Bango watershed areas. Management model that will be applied to the upper Bango watershed is reforestation. Reforestation is one action in watershed management as resource land. It should be related to other relevant measures to obtain optimum results. Reforestation aims to regulate or control the direction of the desired watershed in order to avoid undesirable things (ex. floods and landslides). Utilization of GIS (Geographical Information System) as a research tool will be able to facilitate the identification of threatened watershed areas that need a priority handling.

Keywords Erosion, Agroforestry, Reforestation

Introduction

Watershed management plan is a comprehensive approach that encapsulates all the aspects related to the water resources, which in turn affects water quality and quantity aspects (Tejo Yuwono, 2006). The case study of this paper is appointed upper Bango watershed, which is one of the main basins in East Java. Nature and existence are considered to be important on existing ecological systems. Bango River spring water is sourced from the Brantas river with an average depth of 12-20 meters and has a current speed of 0.3 to 0.4 m/sec (dry season) or 2 to 2.2 meters/second (the rainy season).

On 2003, Bango upper watershed has an average erosion rate of 126.81 ton/ha/year (BP DAS Brantas, Engineering, and Field Plan rehabilitation and Soil Conservation, 2003) that is significantly different from the tolerance threshold of 12.5 ton/ha/yr. The river lies in Malang district and Pasuruan. Bango watershed, as one of primary drainage channel that exists in Malang, makes the role of conservation areas deemed vital and requires special attention, especially upstream. Upland conservation areas have to be protected in order to maintain a stable water cycle and secure the presence of groundwater.

The watershed management model that will be applied to

upper Bango watershed is reforestation. Reforestation is one of the actions in the watershed management as the land resource. Reforestation should be related to other relevant actions to obtain the adequate result. Reforestation and its supporting actions aim to control the direction of the desired watershed so that it can avoid undesirable things (such as floods and landslides) (Tejo Yuwono, 2006). According to the general sense, the 'greening' and 'reforestation' are not essentially different. The difference lies only in the state where both types of activities are performed. Greening worked on farms, especially smallholder agriculture, meanwhile reforestation is being done in the forest area (Notohadiprawiro, 1980).

Agroforestry is a good land management system by improving crop yields cropping land through the merger of income, including the trees plantation, forests and crops or livestock in cropping or rotating on the same plot of land, and management procedures implementation is normally done in harmony with the local (King, 1970). Agroforestry management system has two main objectives that have a synergy; the preservation and improvement of the location and at the same time optimize the joint production of crops agriculture and forestry. Agroforestry which aims to exploit land can provide the best result. This system has two main targets: the principal agricultural yields, as well as forestry that creates a harmonious environment while earning extra yield.

Agroforestry development of Bango watershed is directed to the upstream region, because it is vital area and has special character as 'land degradation'. Bango watershed conditions also on less than ideal level because the average erosion rate is 126.81 tons/ha/year (BP DS Brantas, Engineering and Field Plan Rehabilitation and Soil Conservation,2003) that is far above the tolerance threshold of 12,5 ton/ha/yr.

Generally, the management of the upstream is directed to protected areas (including Bango watershed). However, the development towards protected areas tends to be less effective because, after the reforestation program, sustainability management is also ended. In addition, the land acquisition increasingly forces the function of the existence of the upstream area. Therefore, it needs a model of reforestation that is good for the society, can sustain economic values and maintain the environmental quality of the catchment area that makes up the 'river head area'. Finally, the concept of planning agroforestry can help resolve the complexity of protected areas in the upper Bango watershed areas.

Literature Review

Definition of watershed

The river is one of the water resources that has an important function to life and human life. According to Soejono Sosrodarsono (1985), the river is a combination of river flow and streams, that river flow is a long flow into earth's surface from rainwater. The river consists of watersheds, the basin, river border, and riverbanks which is an integral ecosystem.

According to Asdak (2002:4), A watershed is a geographic area that drains to a common point, which makes it an attractive unit for technical efforts to conserve soil and maximize the utilization of surface and subsurface water for crop production, and farmers whose actions may affect each other's interest.

Definition by the function is divided into several sections, first is watershed upstream, have functions to keep watershed environment condition that not degraded. Conservation functions indicated on the condition of watershed land vegetation cover, water quality, the ability to store water (debit) and rainfall. Second, the center of the watershed based on the function as river water can manage to benefits of social and economic thing. That indicates water quantity, water quality, the ability to deliver water, groundwater levels, management of water infrastructures such as rivers, reservoirs, and lakes. Third, watershed downstream as river water has benefits to social and economic, that indicated from quantity and quality of water, the ability to deliver water, the height of rainfall, and related to the needs of agriculture, water supply, and water management waste.

Definition and classification of Erosion

Erosion is the event of lost or eroded land or parts of land from a place which is transported to another place, either caused by the movement of water from a place that is transported to another place, or wind (Arsyad, 1989).

Two causes of the erosion are natural erosion and erosion because of human activity. Natural erosion can happen because the process of soil formation and its process to maintain the natural balance of the land and usually still supply media for ongoing

Source	Type of erosion or degradation process
Water	Raindrop Splash
	Sheet Erosion
	Rilling
	Gullying
	Stream/Channel Erosion
	Wave Action
	Piping dan sapping
Ice	Solifluction
	Glacial Scour
	Ice Plucking
Wind	Wind erosion cannot be classified by "type" but have various of degree
Gravitation	Creep
	Earth Flow
	Avalanche
	Debris Slide

Table 1. Causes and types of erosion (Gray and Sotir, 1996)

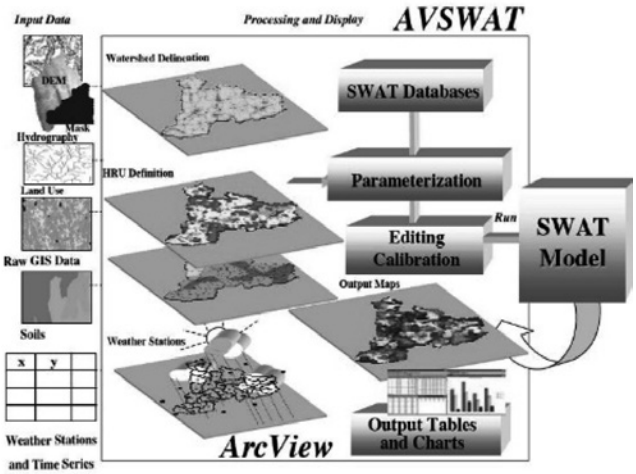


Figure 1. Model data structures in AVSWAT

(Source: *https://geo.arc.nasa.gov/sge/casa/hydrologic/swat.html*)

growth of most plants and medium erosion happen because of human activities that by peeling surface of the land, because ways of farming that not heed the rules of land conservation.

As for erosion control, in principle, can be managed with:

- Reducing thrust or traction, with reducing flow velocity of water on the soil surface, or with reducing the energy of water flow in the affected area
- Raising erosion resistance to protect or strengthen the soil surface with a suitable cover, or by increasing the strength of the bonds between soil particles.
- Enlarging soil infiltration capacity, so that the speed can be reduced runoff.

Research Method

AVSWAT 2000 (Arc View Soil and Water Assessment Tool)

AVSWAT 2000 (Arc View Soil and Water Assessment Tool) is a software-based Geographic Information System (GIS) ArcView 3.2 or 3.3 (ESRI) as an extension (graphical user interface). The program issued by Texas Water Resources Institute, College Station, Texas, USA. ArcView is one of many programs based Geographic Information System (GIS).

AVSWAT 2000 program is development program from an earlier version, SWAT (Soil and Water Assessment Tool), that not work in ArcView software. AVSWAT designed to predict the effects of land management on the flowing water, sediment, and agricultural land in complex components of watershed like soil type, land use, and land management conditions periodically. For modeling purposes, AVSWAT program enables users to divide a large watershed area into several parts of subwatershed to simplify the calculation.

The data structure used as a representation of original condition the appearance objects on earth. In database processing, AVSWAT 2000 divided into two groups: the type of spatial data that the database structure and database vectors in the structure of the grid/ raster.

Agroforstry Concept

Agroforestry is a collective name for technology systems and technology of land use in which woody plants seasonal (*trees, shrubs, palms, bamboo, etc*.) and food plants seasonal or livestock has grown on the same land in some form of arrangement space and time (Nair, 1993).

Characteristic of agroforestry is having interaction between the components of ecology and economy. Michon and de Foresta (1995) said Agroforestry subdivided based its complexity elements, simple agroforestry, and complex agroforestry.

Simple agroforestry is farming system that combine elements of a tree that has economic importance (such as *coconut, rubber, clove, teak*) or has ecological importance (*dadap, Gamal, petai china*) with element of seasonal plants (*rice, corn, vegetables*) or other crops such as *bananas, coffee, cocoa* that has economic value too.

Complex agroforestry is a system that consists of elements

trees, shrubs, seasonal crops, and grasses. Physical appearance and dynamics in complex agroforestry are similar to the forest ecosystem.

Based on a combination of agricultural crops and forestry crops, agroforestry can divide into several forms, (Vergara, 1982b):

1) Silviagricultur

   Silviagricultur is a form of agroforestry that mix between food crops (rice, corn, vegetables, etc.) with forest trees on the same land.

2) Silvipastura

   Silvopastura is a combination of planting trees with forage crops on the same land.

3) Silviofishery

   Silvofishery is a combination of planting forestry to fisheries on the same land.

4) Silviagripastura

   Silviagripastura is a combination of components forestry, agriculture, and livestock on the same land. The results obtained are food, fodder and forest products.

5) Silviagrifiseri

   Silviagrifiseri is agroforestry form that mix forestry, agriculture, and fisheries on the same land. The results obtained are food, forest products, and fish.

Results of Research

Analysis with GIS (AVSWAT 2000)

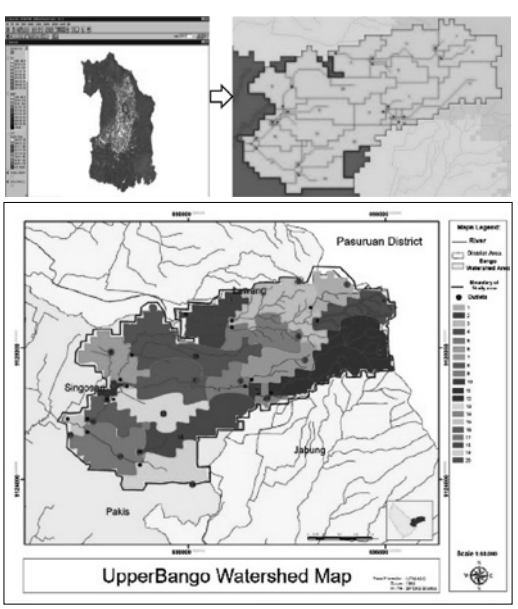


Figure 2. 20 outlets of the sub on Bango watershed

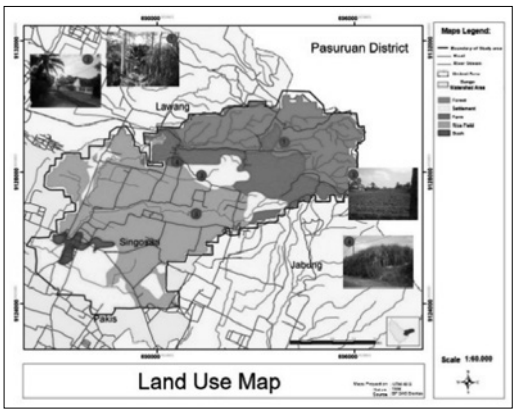


Figure 3. Land use of Malang Regency district

For make delineation, several data needed is stream river, slope, and Bango watershed catchment area. Results of delineation obtained that upper Bango watershed area has 20 outlets and 20 sub-watersheds with each character. The end result of the analysis will develop to make zoning of capabilities and compatibility land. Then that zoning areas will plan with agroforestry concept.

Analysis of Erosion with USLE (Universal Soil Loss Equation)

After analyzing data using AVSWAT program, the delineation data reanalyzed to determine the level of erosion in the studied area using the analysis of *Universal Soil Loss Equation* (USLE) calculation. The USLE equation is a tool used to estimate average annual soil loss caused by sheet and rill erosion). The USLE Equation is:

$$\mathbf{A = R \times K \times LS \times C \times P}$$

With:

A = Predicted soil loss (tons per acre per year)

R = Rainfall and runoff factor by geographic location (mm per acre per year)

K = Soil erodibility factor,

LS = Slope length-gradient factor (length and steepness)

C = Crop/vegetation and cover management factor

P = Conservation practice factor

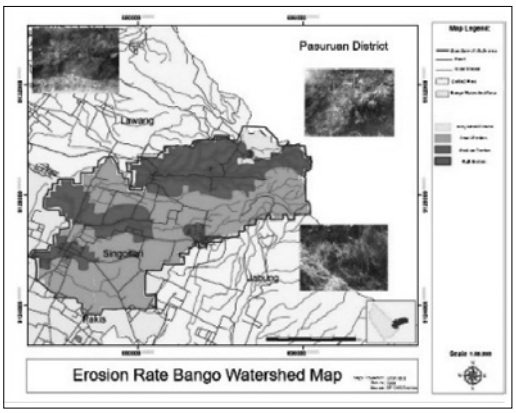


Figure 4. Rate of upper Bango watershed erosion

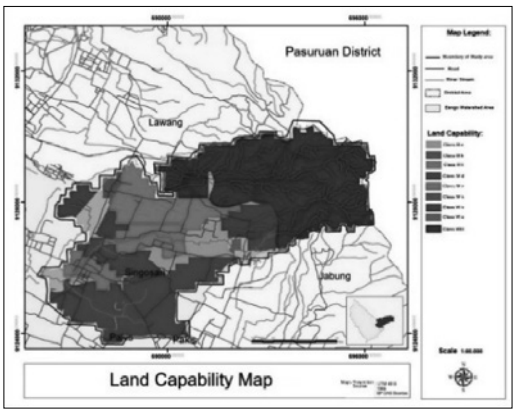


Figure 5. Analysis of land capability of upper Bango watershed which uses overlay model (Arc-GIS)

Based on the USLE calculation, the average rate of erosion in the upper Bango watershed is 62.3581974 ton/ha/year, it's classified in the 'medium erosion'. The classification level of erosion divided into four classifications: very small, small, medium and high.

Agroforestry concept is a method that can reduce the rate of erosion at upper Bango watershed. Agroforestry-based regional planning effort requires an analysis of land (both the ability and compatibility of land) by 'overlay' method of the data (soil type, slope, erosion, effective depth, drainage and rock) thus its purpose to suppressor of the rate of erosion in the area upper Bango watershed can be actualized optimally.

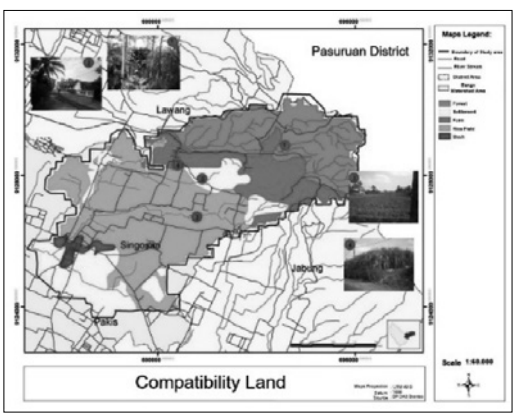


Figure 6. Compatibility land analysis of upper Bango watershed which uses Overlay Technique (SK, Minister of Agriculture No. 837 / Kpts / UM / II / 1980 and No. 683 / Kpts / UM / II / 1981)

Analysis of Land Capability

Evaluation of land capability is a way to use land according to its potential. Assessment of the potential land is needed for policy making, utilization, and sustainable land management. To develop it, required land capability map. Analysis and evaluation of capability land supporting the process of preparation land use planning in a region that is arranged quickly and precisely as the foundation in overcoming conflicts of land use or utilization of natural resources (Suratman et al, 1993).

Analysis of land capability used the Ministerial Environment Decree No. 17 2009 on Guidelines for Determining Environmental Carrying Capacity in Regional Spatial Planning. In this case, will be analyzed 7 variables of capability land that is: soil texture, slope surface, effective depth, drainage, erosion, gravel, and flooding in the area of the upper Bango watersheds.

Land capability analysis is divided into several capability land classifications with its limiting factor. The Result of upper Bango watershed capability analysis classes ranges from class III to class VII. The inhibiting factors at each grade level include slope, erosion, depth, drainage and soil texture. The final results in determining the sub-watersheds that are appropriate (based on the overlay area along the existing policies) to developed with agroforestry concept resulted in 10 sub-watersheds that suitable. Sub-watershed that suitable for use with the agroforestry concept is sub-watershed 2, 9, 10, 13, 14, 15, 16, 17, 18 and 19.

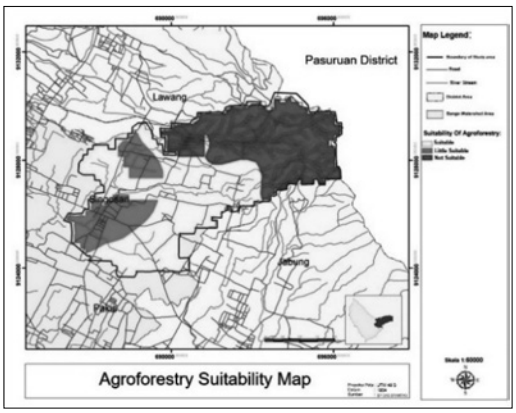


Figure 7. Result of Analysis of agroforestry suitability land of upper Bango watershed which uses overlay model (Arc-GIS)

Agroforestry Landscape Concepts and Management in Upper Bango Watershed

Landscape management by empowering upstream catchment area is expected to improve the productivity of the region and the downstream relationship with harmony and sustainable. As for regional, land-use diversity, beauty, culture, and landscape agroforestry potential eco-village are seen as a variable that has potential to develop eco-tourism in addition to the conservation area (Arifin et al, 2009).

Triple Bottom Line Benefit management is a system that implemented on the Bango upper watershed. Which based on the *Agroforestry* concept, that output target is harmonization of agroforestry development based on landscape watershed from upstream to downstream.

1) Conservation of the environment

   The level of erosion in the upper Bango watershed has an average erosion 62.3581974 tonnes/ha/ year, then the rate of erosion in the upper Bango watershed is classified as 'medium erosion'. Therefore, the upper Bango watershed feasible to developed into environmental conservation.

2) Increased public welfare

   The base concept that will use in upper bango watershed is agroforestry system. A concept that combines an element of agroforestry and agriculture as the cornerstone of development in the upper Bango watershed areas and economically valuable.

3) Preservation of cultural and social

   In addition, the economic sector of the target implementation, other targets are sociocultural preservation that implemented by involving the community as the main subject of the program. Then its emerge a sense of belonging and the creation of the character building for the ecological environment.

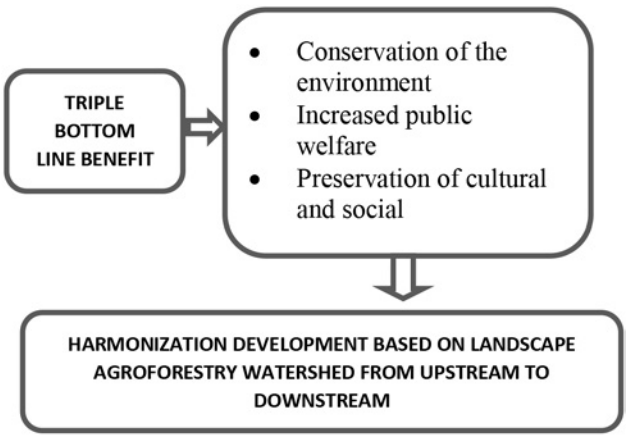


Figure 8. Integrated area management in the upper Bango watershed with agroforestry concepts

No.	Pattern Classification Crops
1	**Basic Corps;** forestry plants intended for wood production, the determination of rotations for 5 years. Types of plants selected are the type sengon (Faraserianthes falcataria). Besides sengon plant species that has great potential to be used is bamboo. Where bamboo can absorb rainwater up to 90% compared to the rainwater that ranges from 35-40% (Wahyuddin, 2008).
2	**Seasonal Corps (Step I);** short rotation crops were planted among the main crop with a minimum distance of 30 cm from the main plant stem. Timely planting carried out in the first year / before the main crop one year of age, the type of plants that have fruit trees such as bark, mango, and sapodilla. It is intended to obtain non-timber products (fruit)
3	**Seasonal Corps (Steps II);** short rotation crops that can be grown with/without shade, harvesting seasonal crops planted after first stage (fruit trees) until the time limit of staple crop was two years old. Types of plants selected food crops (horticulture) such as corn, tomatoes, eggplant, peanuts, and soybeans.

Table 2. Planting pattern classification based on agroforestry concepts

Pre-Implementation

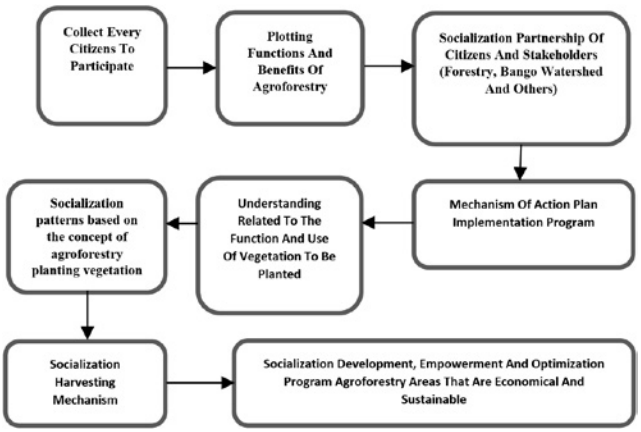
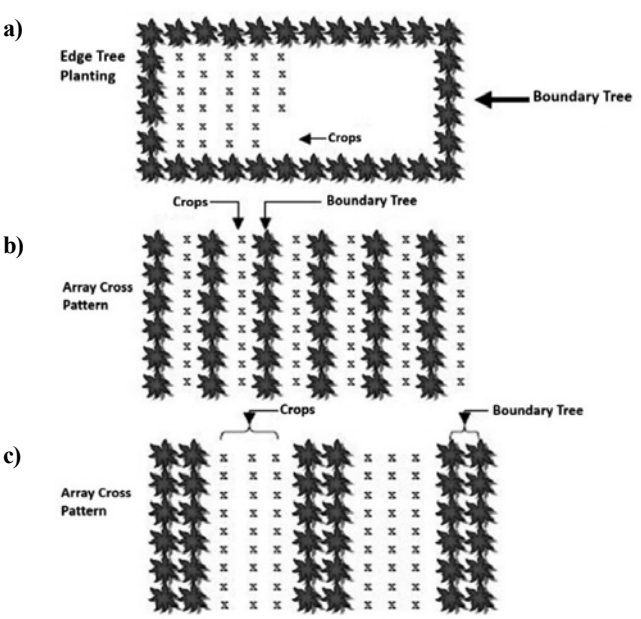
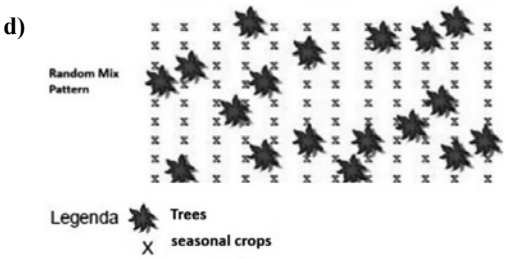


Figure 9. Socialization referralprogram implementation in the upper Bango watershed agroforestry

Implementation

Based on a combination of agricultural crops and forestry crops cultivated, agroforestry can be divided into several forms, namely silviagrikultur, silvipastura, silvifishery and silviagripastura (Vergara, 1982b). The type of agroforestry that can be applied to the upstream watershed is silviagricultur. A form of agroforestry that is a mix of business between food crops (rice, corn, vegetables, etc.) with plant forestry on the same land. The combination of these efforts can be carried out by way of setting.





Function	Jenis Tanaman
Control Erotion	Sengon Sea, Waru Mountains, Marmoyo, Giyanti, Hope, Kemlandingan, Johar, Mindi, Balsa, Bungur, Alingsem, Eucalyps, Laban, Pecan and Damar
Controlling Landslides	Tekik, Pilang, Asem, Tanjuman, Trengguli, Sono Keling, Sisso Sono, Sono Kembang, Mahogany broad leaves, Rengas, Kesambi and Teak
Crops fruit trees - fruit / advocated for the preservation of agricultural land and water	Cloves, Cashew, guava, rambutan, soursop, avocado, jackfruit, and Aren
For the purpose of providing forage	Elephant Grass, Sentro, Stilo, king grass, Setaria grass, Bahia grass
Crops riverbank reinforcement and retaining landslides	Aren, Bamboo, Kaliandra, Gamal, Salak, Rattan

Table 3. Recommended crop types based on land function

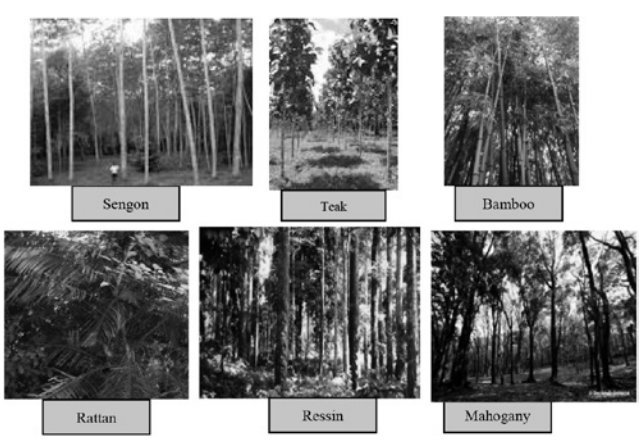


Figure 10. Recommendation of crops for medium erosion

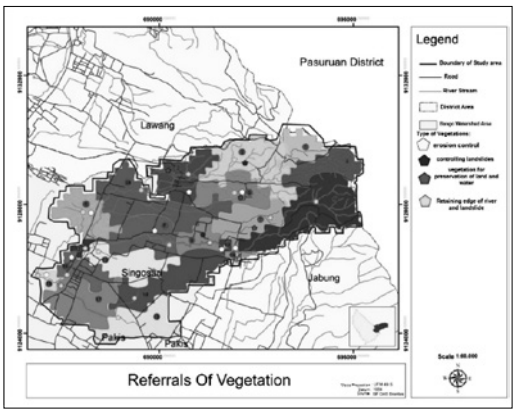


Figure 11. Referrals of vegetation on upper Bango watershed

Monitoring and evaluation

With the monitoring and evaluation on a regular basis, it is expected that an execution error will not be protracted and could be corrected immediately. The objectives of this monitoring are:

1) To control the implementation of activities and use of natural resources in upstream Bango watershed with agroforestry concept.
2) To push the mechanism of self-control of the perpetrator program management of natural resources in the upstream Bango watershed with agroforestry system.
3) To monitor the activities of the stakeholders in upper Bango watershed condition against reform-purpose resources primarily managed with agroforestry techniques.

Parameter monitoring and evaluation (including criteria and indicators) must be relevant to methods or tools that used in research or the results of the development program. For tools that used in monitoring and evaluation are:

1) To know the role of trees that used in Farming system analysis in the upper Bango watershed.
2) To determine the role of trees in agricultural landscapes using agroecosystem on upper Bango watershed.
3) To determine the impact of the tree-based system on the diversity and sustainability of results towards improving the socio-economic and environmentally beneficial on upper Bango watershed.

Conclusion

Based on the calculation, the limit of acceptable erosion rate is 12.5 tonnes/ha/year. Based on the USLE calculations, the average rate of erosion in Bango upper watershed is 62.3581974 ton/ha/year, the rate of erosion in the upper watershed is classified as 'medium erosion'. With high erosion rate and compared with the tolerance limit allowed erosion (12.5 tonnes/ha/year) will require special conservation to control erosion.

Land ability analysis is divided into several classes of land capability with some limiting factors. The result of the analysis, the capability of upper Bango watershed classes from class III to class VII. The limiting factors at each grade level include slope, erosion, depth, drainage and soil texture. The land compatibility analysis resulted that in the Bango Upper Watershed the study area divided into 4 areas: the protected areas, buffer zones, and the cultivation of annual crops cultivated area year. In determining the sub-watersheds, that is appropriate (based on the overlay area along the existing policies), to develop the concept of agroforestry there are 10 sub-watersheds that suitable. Sub-watershed that suitable for use with the concept of agroforestry is: sub-watershed 2, 9, 10, 13, 14, 15, 16, 17, 18 and 19.

The concept of agroforestry is a method that can reduce the rate of erosion in the upper Bango watershed. Planning program based Agroforestry later divided into two stages are implementation and monitoring-evaluation. For implementation phase, that includes 5 stages are Determination of vegetation will be planted, empowerment and optimization program agroforestry, determining the planting pattern to be used in the upper Bango watershed, briefing and dissemination of program implementation, team building (concept, implementing, monitoring and evaluation).

Monitoring and evaluation, the tools used that farming system analysis (monitoring and evaluating the role of trees in upper Bango watershed), agroecosystem analysis (monitoring and evaluating the role of trees in the landscape of and tree-based system (monitoring the impact of the tree-based system the diversity and sustainability.

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