Nitrogen flows due to human activities in the Cianjur-Cisokan watershed area in the middle Citarum drainage basin, West Java, Indonesia: A case study at hamlet scale

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Abstract

This paper demonstrates a methodology to estimate nitrogen flow due to human activities in three rural hamlets located at different elevations in the Cianjur-Cisokan watershed area, West Java, Indonesia. The rural ecosystem in each hamlet was divided into several components and material transfers between components due to human activities were estimated, mainly by interview, and converted to nitrogen. Then a component model of nitrogen flow in each hamlet was constructed. Nitrogen balances of the three hamlets were positive: 87-267 kg N ha^{-1} $year^{-1}$. Two indices, NSENO (nitrogen surplus per unit edible nitrogen output) and NSEEO (nitrogen surplus per unit edible energy output), were newly proposed. These indices showed that nitrogen surplus of the hamlet with the lowest altitude where paddy fields are dominant was the least when producing crops with the same nutritional value as those grown in other hamlets. Application of unused local resources, mud and human excrement, can reduce nitrogen surplus by 49-96 kg N $year^{-1}$ ha^{-1} and can provide subsidy of US$ 310-370 $year^{-1}$.

Key words: rural ecosystem; nitrogen flow; nitrogen balance; local resource

1. Introduction

A number of traditional land use systems in the humid tropics have been evaluated as agroforestry systems (Nair, 1985) that allow sustainable biological production without generating environmental degradation. The humid tropics in Southeast Asian countries have experienced rapid population growth in the last several decades, which requires food production increase. Economic growth in these countries during the 1970s and 1980s allowed introduction of modern high-input intensive agricultural systems that may cause environmental impact.

In the case of West Java, Indonesia, which is one of the most densely populated areas in the world, traditional Javanese home garden (locally called *Pekarangan*) and traditional rotation cropping system (*talun-kebun* system) have been evaluated as ecologically sustainable agroforestry systems (Fernandes and Nair, 1986; Abdoellah, 1990; Karyono, 1990; Christanty *et al.*, 1996). It has, however, been suggested in recent years that the structure and function of the traditional home garden, which are generally considered to have contributed to its sustainability, have been altered as a result of social and economic changes, such as urbanization and expansion of the market economy (Arifin *et al.*, 1997; Arifin *et al.*, 1998a; Arifin *et al.*, 1998b; Michon and Mary, 1990). The lower sustainability of *talun-kebun* system due to intensification of the crop cultivation is also a matter for concern (Christanty *et al.* 1997). Moreover, increasing population pressure and shortage of land are forcing peasants to cultivate steeper slopes that were formerly covered with forest, causing major erosion problems and giving only small, short-term returns. Under the current social and economic circumstances of rural area in Indonesia, West Java in particular, a simple return to the traditional land use systems is not likely to be a practicable solution. It is essential to reconstruct a modified sustainable land use system that is practicable under existing conditions, especially through an understanding of the processes that support sustainability of the traditional land use systems.

To tackle the problem as described above, the initial step necessary to be undertaken is to elucidate the current condition of the rural ecosystem in relation to the issues of sustainability in agriculture-related human activities. One of the most frequently employed indicators of land use sustainability is soil nutrient balance. A highly positive balance can result in pollution of ground water and surface water, while a negative balance may lead to mining of the soil nutrient stock and subsequent loss of soil fertility (De Koning *et al.*, 1997). Researchers have estimated soil nutrient balance in several spatial scales: supra-national scale (Stoorvogel *et al.*, 1993), sub-national scale (De Koning *et al.*, 1997), district scale (Smaling *et al.*, 1993), village, and field scale (Krogh, 1997) in Africa and South America. For traditional land use systems in Indonesia, field scale surveys in home gardens (Jensen, 1993a; Jensen, 1993b) and *talun-kebun* system (Christanty *et al.*, 1997; Mailly *et al.*, 1997) have estimated not only nutrient balance but also nutrient cycling, assessing its sustainability and elucidating the factors that support the sustainability. Though it is suggested that the spatial scale at which these estimations are made is significant (Krogh, 1997), estimation of nitrogen flow or nitrogen balance at larger spatial scale has not been carried out in Indonesia. The rural landscape in Indonesia is a mosaic of agroecosystems, usually consisting of several interacting components. Thus, estimation at larger spatial scales should comprise these several components.

In this study, a rural hamlet is defined as a unit of rural ecosystem, which consists of several types of land use, livestock, and humans. In order to evaluate the rural ecosystem holistically, focus was given on “artificial” nitrogen flows due to human activities, mainly management in biological production system and food consumption, because these flows can be easily estimated through interview.

The objectives of this study are as follows: (1) to estimate the quantity of nitrogen flows due to human activities as a component model in three hamlets along a terrain gradient of the Cianjur-Cisokan watershed area, West Java, to elucidate the current condition of the rural ecosystems, and (2) to evaluate rural ecosystem sustainability at hamlet-scale in terms of artificial nitrogen balance.

In this study, artificial nitrogen flow was defined as nitrogen flow due directly to human-induced material transfer processes such as fertilizing arable lands, harvesting crops, purchasing food, collecting/feeding fodder grass, exporting livestock, etc. Nitrogen flows related to soil nutrient balance as shown in a series of study (e.g. Stoorvogel *et al.*, 1993) are summarized in Table 1, from which Mineral fertilizer (IN1), Organic fertilizer (IN2), Harvest products (OUT1), and Removed crop residues (OUT2) were taken into account in this study as artificial nitrogen flows to/from the land-use components. Natural processes of nitrogen flow (atmospheric deposition, IN3; biological fixation, IN4; sedimentation, IN5; leaching, OUT3; gaseous losses, OUT4; and erosion, OUT5) are also important. Nevertheless an approach taking into account only the artificial nitrogen flows would provide significant insight, since generally, artificial nitrogen inputs (IN1 and IN2) in agricultural lands play major role more than that of the natural process in terms of quantity of nitrogen (Table 1). Moreover, nitrogen losses due to OUT3 and OUT4 from agricultural lands are closely related to nitrogen input through fertilizing (IN1 and IN2). For instance, (IN1+IN2) was used as an important parameter in the transfer function for calculating OUT3 and OUT4 (Stoorvogel *et al.*, 1993; Smaling *et al.*, 1993; De Koning, 1997). In addition, nitrogen losses from paddy fields are generally described as percentage of nitrogen input through fertilizers (e.g. Buresh *et al.*, 1991; De Datta, 1995). Nitrogen output through erosion (OUT5) is important only where soil erosion occurs frequently, and often omitted from consideration (e.g. Jensen, 1993; Mailly *et al.*, 1997). No obvious signs of erosion were observed in the study hamlets. Thus, we would be able to guess OUT3 and OUT4 indirectly from artificial nitrogen flows to a certain extent.

We hypothesize that the rural ecosystem in the study area has already become an open system, in terms of nitrogen flow, under the influence of market economy, and that it is no longer a closed system with self-supporting functions. Therefore, enlargement of the spatial scale is necessary to reconstruct a new material flow, especially nitrogen flow, system, to the extent that stability and sustainability of biological production could be maintained without causing environmental degradation.

2. Methods

2.1. Study area

The study was carried out in Cianjur-Cisokan watershed area of Cianjur district, located in the central part of West Java, Indonesia (Fig. 1). The Cianjur river and the Cisokan river are tributaries to Citarum river, which has the largest catchment area in West Java. The Cianjur-Cisokan watershed area is situated in the middle part of the Citarum drainage basin, extending on the east-facing slope of Mount Gede (2,958 m), which is an active stratovolcano with broad footslope formed by volcanic debris flow (“lahar”). Major landforms in the watershed are the volcanic edifice, lahar plateau, and laharic flood plain (Tamura and Kitamura, 2001). Because of the altitude difference, the watershed contains several bio-climatic conditions.

Three rural hamlets, Galudra (ca. 1,200 m asl), Mangunkerta (ca. 950 m asl), and Selajambe (ca. 300 m asl), were selected for the case studies (Fig. 1b), so as to sample different types of nitrogen flow according to landscape structure. General information on villages in which the study hamlets are located is shown in Table 2. Galudra and Mangunkerta are located on the lahar plateau and Selajambe on the laharic floodplain and natural levee. Taking advantage of the highland climate, Galudra is dominated by upland fields planted with cash crops such as carrots, spring onions, and chilies (Fig. 1b). Selajambe, at the lowest altitude of the three hamlets, is dominated by paddy fields. Mangunkerta is located at the ecotone between the paddy-field–dominated and the upland-field–dominated landscapes. Landscape structure of Mangunkerta is complex and heterogeneous, whereas that of Galudra and Selajambe is homogeneous.

Temperature was measured in each hamlet from August 1999 to August 2000 (143 days, 213 days, and 341 days at Galudra, Mangunkerta, and Selajambe, respectively; Sakaida, personal communication). An average temperature of ca. 21℃ was reported for Galudra and Mangunkerta and of ca. 25℃ for Selajambe. The year consists of a dry season (May to September) and a rainy season (October to April). One weather station at Pasir Sarongge (ca. 1,200 m asl), which is located 1.5 km north of Galudra, records a mean annual rainfall of 3,390 mm. The Cihea weather station (ca. 250 m asl), which is located 4.0 km east of Selajambe, records a mean annual rainfall of 1,960 mm.

Biological production occurs under several types of land use: home garden (*Pekarangan*), mixed garden (*Kebun campuran*), forest garden (*Talun*), upland field

(*Tegalan*), and paddy field. A home garden is an area of land surrounding a house with a boundary, in which several annual and perennial crops, such as fruits, vegetables, starchy crops, and timber woods, are cultivated. It often includes small livestock shelters or fishponds. A mixed garden, on the other hand, is an area of land outside the village settlement, where perennial crops, mostly trees, are planted, and under which annual crops are cultivated (Karyono, 1990). A forest garden is usually located on a steep slope, where management is quite extensive, and where bamboo trees are dominant. Upland fields in the study hamlets are terraced, where vegetables, pulses, and starchy crops such as carrots, spring onions, chilies, maize, flowering white cabbages (*Brassica rapa*, local name: Caisin), tomatoes, peanuts, kidney beans, asparagus beans, cassava, potatoes, and sweet potatoes are cropped or often are intercropped. These crops are usually harvested 2-4 times a year. Trees of papaya and banana are sometimes planted on the edge or boundary of the upland fields. In paddy fields, generally, rice is cultivated twice a year (April-July and October-January). Soybean, peanut, maize, and cassava are grown during the period in between. Trees of coconut and banana are often planted along the boundaries of the paddy fields. Outside of the villages, primary and secondary forests extend up the slope above Galudra, and a vast tea plantation is located on the slopes above Mangunkerta.

Settlement of Galudra is the newest among the three hamlets. In the 1950s, people settled into lands that were formerly cultivated as upland fields after clearing the forests. Settlement of Mangunkerta was established in the 1940s whose former land uses were tea plantations, mixed gardens, upland fields, and paddy fields. Settlement of Selajambe is the eldest of the three hamlets. This hamlet was established in the 1930s on natural levee that was formerly used as mixed gardens.

2.2. Framework for a component model of the rural ecosystem

The rural ecosystem in each hamlet was divided into 9 components: human, home garden, fishpond, livestock, mixed garden, forest garden, paddy field, upland field, and dump. Although fishponds are usually located within the boundaries of home gardens, we separated the two in order to evaluate the ecological function of the fishpond. "Dump" was defined as a component into which materials such as garbage or mud are dumped. Material transfers between components due to human activities were estimated from data obtained through interviews.

2.3. Interview for estimation of material flow between components

We randomly selected 60 households in each hamlet for survey by interview through a questionnaire to determine the following: (1) the status of biological production and the utilization of biological resources; (2) the import and export of food, fertilizer, and fodder into and out of the hamlet through market; and (3) some general characteristics, such as status of land ownership.

A questionnaire, formulated earlier by Abe *et al.* (1999), was revised to fit the conditions of the Indonesian rural area under study. Biological production was divided into 7 components: home garden, mixed garden, forest garden, upland field, paddy field, livestock, and fishpond. Contents of the questionnaire are summarized in Table 3. The area of each home garden, house, fishpond, and livestock shelter were measured directly.

2.4. Estimation of mud accumulation at the bottom of fishponds

Mud that accumulates at the bottom of fishponds is commonly removed and dumped in the home gardens or elsewhere where it may function as fertilizer.

To estimate the quantity of mud removed from fishponds, sieves covered with fine mesh (50 μm) were placed at the bottom of each selected fishpond for 1 month (July 3 through August 3, 2000) in dry season, and 1 month in rainy season (April 6 through May 5, 2001). Three fishponds were sampled in each hamlet, for a total of 9 fishponds. Three sieves were set at the inlet, outlet, and middle part of each sampled fishpond, for a total of 27 sieves. After removal of sieves, the mud was weighed. The mud was then dried, weighed again, and sent to a laboratory for chemical analysis to determine its nitrogen content. Mud accumulation (kg m^{-2} $month^{-1}$) in all the sieves was averaged for each hamlet and multiplied by the number of months during a season (5 for dry season: May-September; 7 for rainy season: October to April) to estimate the annual accumulation per area. The annual mud accumulation per area (kg m^{-2} $year^{-1}$) was multiplied by the total area (m^2) of the fishponds in each hamlet to estimate the total accumulation for each hamlet (kg $year^{-1}$).

2.5. Conversion from wet weight to nitrogen and energy

Data obtained from the interviews and estimations of mud accumulation were converted to quantities of nitrogen and energy using an Indonesian food composition table (Mahmud *et al.*, 1990; Hardinsyah and Briawan, 1990). A Japanese food composition table (Kagawa, 1999) was also used for items that could not be found in the Indonesian data tables. Typically, data in food composition tables are reported as energy content per 100 g of edible portion. Unfortunately, no data were available for the inedible portions of the main products. Therefore, we defined N (all), N (edible), energy (all) and energy (edible) as follows:

N (all) = (wet weight) × (nitrogen content (%)) /100

N (edible) = (wet weight) × (ratio of edible portion) ×(nitrogen content (%)) /100

Energy (all) = (wet weight) × (energy content (%)) /100

Energy (edible) = (wet weight) × (ratio of edible portion) × (energy content (%)) /100

N (all) and energy (all) are calculated on the assumption that the nutritional composition of the inedible portion is the same as the edible portion. N (all) and energy (all) are not real values of nitrogen and energy, but are defined against underestimation when using N (edible) or energy (edible).

Fuel wood, fodder, animal excrement, fodder grass, crop residues, and mud were analyzed. Dry weight was measured after drying for 48 h at 105 ℃. Nitrogen contents of all samples were obtained by chemical analysis.

Material flow via animal bodies, i.e. selling livestock to the market, was also estimated. The number of the each type of animal exported was multiplied by average body weight and its nitrogen content. Data on average body weight of each type of animal in each hamlet was taken from Mansjoer and Hayashi (2001). Data on nitrogen content in animal body was taken from Morimoto (1969).

Nitrogen balance of a normal adult human body is generally zero (Garlick and Reeds, 2000). Human excrement was calculated as 90% of N (edible) intake, because nitrogen loss includes sweat and desquamation which account for 1-8% of nitrogen needed to achieve nitrogen equilibrium (Garlick and Reeds, 2000), and because nitrogen intake of infant is generally larger than nitrogen loss due to body growth.

2.6. Total input-output analysis at hamlet scale

Regarding each hamlet as a unit of rural ecosystem, the total nitrogen input and output of the hamlets were estimated to determine the nitrogen balance as a consequence of artificial nitrogen flow, in order to evaluate and compare the sustainability of the rural ecosystem. All the external inflow/outflow of each component were summed up to determine the total input/output of each hamlet.

Additionally, to evaluate sustainability in terms of nitrogen balance in relation to productivity of food resources, two indices of surplus nitrogen loading were defined: nitrogen surplus per unit edible nitrogen output (NSENO) and nitrogen surplus per unit edible energy output (NSEEO). The definitions are as follows:

$$\text{NSENO} = (\text{Input} - \text{Output}) / (\text{N (edible) output})$$

$$\text{NSEEO} = (\text{Input} - \text{Output}) / (\text{Energy (edible) output})$$

NSENO indicates how much nitrogen surplus occurs per kg gain of nitrogen (~6.25 kg of protein) in crops from arable land. NSEEO indicates how much nitrogen surplus occurs per GJ of energy in crops from arable land.

These indices not only indicate sustainability in terms of nitrogen balance but are also closely related to food production. The higher the value of the index is, the more nitrogen surplus occurs when producing crops with the same nutritional value.

3. Results and discussion

The total population of the 60 sampled households in Galudra, Mangunkerta, and Selajambe was 303, 351, and 233, respectively. Status of land ownership in sample households is summarized in Table 4. It also indicates percentage of the households that own land that was utilized by themselves and those that leased land. Population density, which was calculated as population of sampled 60 households per total area of land utilized by these households, was 15.1 persons ha^{-1} in Galudra, 78.1 persons ha^{-1} in Mangunkerta, and 21.6 persons ha^{-1} in Selajambe.

3.1. General description of component model of nitrogen flow

By means of the method described in Section 3, a component model of nitrogen flow was constructed. The N (all) flow model of Galudra, Mangunkerta, and Selajambe is shown in Fig. 2a, Fig. 2b, and Fig. 2c, respectively.

All arrows from “Home garden”, “Mixed garden”, “Paddy field”, “Upland field”, “Livestock”, and “Fishpond” to “Human” indicate consumption by human. Arrows to “Human” from outside of the hamlet indicate foods purchased from the market. All arrows from “Home garden”, “Mixed garden”, “Paddy field”, “Upland field”, “Livestock” to outside of the hamlet indicate crops or animals sold to the market, and some of them from “Mixed garden” and “Forest garden” indicate outflow by utilization of fuel wood on the assumption that all the nitrogen in fuel wood is released upon burning. These are displayed with “FW” in Fig. 2. Crops sold at the market include only the main products that were produced. According to the interview, all the crop residues from “Mixed garden”, “Upland field”, and “ Paddy field”, that were not utilized as fodder, except chaff as a byproduct of rice production, were returned to the arable land after being harvested. Chaff was included in the outflow from “Paddy field” because unhulled rice was brought to the rice mill. Nitrogen inputs from outside to “Home garden”, “Mixed garden”, “Paddy field”, and “Upland field” from outside refer to chemical fertilizer, except upland field in Galudra (Fig. 2a), where chicken manure is purchased from outside and used as fertilizer. Arrows to “Livestock” from “Upland field”, “Paddy field”, “Mixed garden”, and “Forest garden” indicate crop residue or grass cut as fodder for sheep, goats and rabbits. Arrows to “Livestock” from outside of the hamlet are rice bran as a fodder fed to poultry. Arrows from “Livestock” to “Upland field”, “Paddy field”, “Home garden”, and “Mixed garden” are animal excrement used in manure as organic fertilizer. Arrows from “Fishpond” to “Home garden”, “Forest garden”, and “Dump” indicate mud removed from “Fishpond” and assume that all the mud accumulated at the bottom of fishponds was removed. The function of mud removal is not negligible in nitrogen flow. It was estimated that a total of 228 kg year^{-1} nitrogen was removed from fishponds in Galudra, 341 kg year^{-1} in Mangunkerta, and 168 kg year^{-1} in Selajambe. All the human excrement was dumped and there was no utilization of human excrement as fertilizer.

3.2. Characteristics of nitrogen flow in each hamlet

Nitrogen flow in Galudra (Fig. 2a) is characterized by overwhelming nitrogen input to “Upland field” via chemical and organic fertilizer. Nitrogen input to “Human” via food from the market and output from “Upland field” via crops exported are also major flow. Internal flow is generally minor, except human excretion and input/output to/from “Livestock”. Large amount of nitrogen flows through “Livestock” indicated a major role of “Livestock” in Galudra in internal nitrogen flow.

The rural ecosystem of Mangunkerta is characterized by a number of nitrogen flow channels, indicating complexity of functional linkage among components through material transfer (Fig. 2b). The most major nitrogen flow is external flow to “Human” from the outside of the hamlet via purchased foods. Human excretion and “Livestock” is playing a significant role in internal flows. “Fishpond” is also contributing to major internal flows. Compared with Galudra and Selajambe, external input to arable land components via chemical fertilizer is relatively minor flow, because percentage of area of these components in the hamlet is small.

Selajambe is characterized by overwhelming input via chemical fertilizer to paddy field and output from paddy field via exported crops. Input to “Human” from the outside via purchased foods, and input to “Livestock” from outside via purchased fodder are also major flows (Fig. 2c). Compared with Galudra and Mangunkerta, internal flows through “Livestock” are not so significant, since “Livestock” in Selajambe highly depends on fodder purchased from the outside market and only small amount of manure is utilized in Selajambe. Livestock’s preference for purchased fodder, i.e. rice bran, is related to majority of poultry in livestock.

On the whole, the most major flow is input of chemical fertilizer to arable land component and food purchased from the outside market. This fact suggests that rural ecosystem should be regarded as an open system in terms of artificial nitrogen flow. However, to some extent, “Livestock”, especially goats and sheep, were still playing a significant role in internal nitrogen flows in Galudra and Mangunkerta. Human excrement was also performing a major internal flow into “Dump” without any utilization.

Compared with Mangunkerta, nitrogen flow in Galudra and Selajambe is simple with fewer flow channels, indicating concentration of nitrogen flow and less functional linkage among the components. Complexity of nitrogen flow channels in Mangunkerta is likely to be related with complex and heterogeneous landscape structure of this hamlet. On the other hand, the simple and fewer nitrogen flow channel of Galudra and Selajambe is likely to be associated with homogeneous landscape structure. It is suggested that complexity of landscape structure is one of the factors that determine the pattern of nitrogen flow.

3.3. Total nitrogen balance of the three hamlets

Table 5 shows that the nitrogen balance in all the hamlets was positive. Surplus nitrogen value in Galudra was the highest (267 kg N year^{-1} ha^{-1}), lowest in Selajambe (87 kg N year^{-1} ha^{-1}), and intermediate in Mangunkerta (239 kg N year^{-1} ha^{-1}). It must be noted that nitrogen balance mentioned here is based on calculations in which only the artificial processes of material flow were taken into account. In fact, natural processes of nitrogen flow, such as runoff, leaching, and denitrification, are considerable, and a great deal of nitrogen outflow from the system would be expected. The high value in Galudra can be attributed to nitrogen balance in upland fields where land is intensively fertilized (Table 6). Food purchased from outside market was the major factor that contributed to nitrogen surplus in Mangunkerta where population density (78.1 persons ha^{-1}) was the highest among three hamlets. In spite of high-input cropping in paddy field (Table 6), there was no excessive nitrogen surplus, as was observed in the upland fields of Galudra. Farmers in Galudra fertilized upland fields with nitrogen 7 times as much as recorded in harvested crops (Fig. 2a). On the other hand, nitrogen input to the paddy fields in Selajambe was only 1.2 times of that recorded in harvested crops. Estimation of nitrogen balance gives 274 kg N year^{-1} ha^{-1} for upland field in Galudra, and 30 kg N year^{-1} ha^{-1} for paddy fields in Selajambe. Intensity of nitrogen input (Table 6) was not significantly different ($p > 0.05$, Mann-Whitney *U*-test; N=43 for Galudra, N=23 for Selajambe), but difference in amount of nitrogen in harvested crops made this difference in nitrogen balance. It should be noted, however, that soybean was frequently planted at the interval of rice cropping in Selajambe, because of symbiotic nitrogen fixation in leguminous species that would influence the net biological fixation. Taking account of this fact, we estimated the net nitrogen balance on the assumption that 60% of the total nitrogen requirement of soybean is supplied through biological fixation (Stoorvogel *et al.*, 1993). Our estimation gave the nitrogen balance of 146 kg N year^{-1} ha^{-1} for paddy field in Selajambe, and 157 kg N year^{-1} ha^{-1} for total of Selajambe, which is still the lowest value in the three hamlets.

NSENO and NSEEO for the three hamlets are shown in Table 7. Both indices were the lowest in Selajambe, highest in Mangunkerta, and intermediate in Galudra, indicating that crops having the same nutritional value can be obtained with the lowest nitrogen loading in Selajambe and the highest in Mangunkerta whose food productivity was quite low. Conversely, to obtain crops with the same degree of nitrogen loading from arable land, the maximum nutritional value can be obtained from a crop produced in Selajambe, reflecting the high efficiency of production in this village. Paddy fields may play a significant role in food production that is accompanied by low environmental risk.

3.4. Prospects for improvement of nitrogen flow in hamlet

3.4.1. Reduction of excessive input of chemical fertilizer

As mentioned above, the most crucial state of nitrogen flow is the excessive input of chemical fertilizer to upland fields in Galudra, which causes the highest nitrogen surplus. Intensive use of chemical fertilizer has increased the crop yields. It can be applied easily and uniformly to crops to supply them with ample amounts of the most essential plant nutrients. Because it meets plants' nutrient needs for the short term, chemical fertilizer, however, has allowed farmers to ignore long-term soil fertility and the processes by which it is maintained (Gliessman, 1998). Moreover, mineral components of chemical fertilizers are easily leached out of the soil, which may cause ground and surface water pollution. Thus, there is a need for reduction of excessive use of chemical fertilizer to a proper level with maximization of nitrogen input efficiency through improvement of fertilizer management. Appropriate use of organic fertilizers such as manure, which contribute not only as substitute for chemical fertilizer but also to long-term soil fertility, also should be promoted.

According to the supplementary information from farmers, preference of chemical fertilizer to manure is due to difficulty in handling manure because of its heavy weight per unit of nitrogen (Table 8). In the case of Galudra, 58t of chicken manure and 8t of urea are used in upland fields, which account for 32% and 58% of the total nitrogen input, respectively. The price of urea is less than half of the chicken manure that contains the same quantity of nitrogen (Table 8). Low price of urea per unit of nitrogen also seems to be one of the driving forces for excessive input of nitrogen by urea. In Galudra, chicken manure is transported from poultry farms in remote places. Therefore, reduction of the transport cost by collecting chicken manure from nearby sources would be effective in promoting the use of chicken manure. Spatial analysis of potential manure production at regional scale is needed to facilitate the accessibility of manure from nearby sources.

3.4.2. Potential of unused local resources

Utilization of unused local resources can contribute to improvement of the nitrogen flow that enhances ecological and socio-economic sustainability of the rural ecosystem, because recycling of waste can reduce the discharge of nitrogen that may cause nitrogen loading, and because it can reduce the cost of living and biological production that depends on market.

There are some local resources that can be used as fertilizer: crop residue, animal excrement, mud from the fishponds, and human excrement. As mentioned above, all of the crop residues, except fodder for livestock, are returned to the arable lands.

Percentage utilization of animal excrement as fertilizer is shown in Table 9. Percentage of using chicken excrement is low as compared to the other animal excrement, because collection of excrement is difficult if chicken is let free to roam around a house. Excrement of roaming chicken, however, is likely to function as fertilizer when dropped on the home garden. All of the sheep and rabbit excrement are utilized as fertilizer in Galudra (Table 9), indicating that the livestock manure is highly utilized. Potential use of livestock manure, except chicken, in Mangunkerta also seems to be high (more than 75%). Although the potential of sheep manure in Selajambe is not utilized to the full (27%), promotion of sheep manure utilization is not likely to be effective because there were only 11 sheep in the sampled households in this hamlet.

On the whole, crop residue and animal excrement have already been highly utilized. Thus, there is not much scope for improvement of nitrogen flow by promoting utilization of these local resources. Yet, the situation is encouraging because it suggests that farmers in this area are willing to accept an animal-based production system. Upscaling of the ownership of livestock should be encouraged not only to gain economical profits but also to increase manure production.

Mud removed from fishponds is not negligible in nitrogen flow (Fig. 2). Mud is similar to chicken manure with respect to C/N ratio (mud: 6-11, chicken manure: 7). Nitrogen removed from the fishponds in Galudra, Mangunkerta, and Selajambe was estimated to be 228 kg year^{-1}, 341 kg year^{-1}, and 168 kg year^{-1}, respectively. The mud is equivalent to 6,900 kg, 10,000 kg, and 5,100 kg of chicken manure, respectively, in terms of nitrogen content. These mud can be regarded as subsidy of US$ 140, US$ 200, and US$ 100, respectively, when utilized to the full extent as a substitute of chicken manure (US$ 1 = 10,000 Indonesian Rupiah). Although this is a rough estimation, the results indicate that this function of fishponds as a source of fertilizer is worth further study.

Human excrement was not utilized in any of the households in the three hamlets. Abe *et al.* (2000) reported that human excrement was generally utilized as fertilizer in a rural village in Sichuan Province, China. In Indonesia, there is a strong cultural constraint for it, but human excrement plays a significant role in internal nitrogen flow, that can be one of the major causes of nitrogen surplus due to food purchase from market (Table 5), and that can be effective in reducing the external dependency on fertilizer. Human excrement can be regarded as subsidy of US$ 210, US$ 200, and US$ 170 in Galudra, Mangunkerta, Selajambe, respectively, when utilized to the full extent as a substitute for urea (US$ 1 = 10,000 Indonesian Rupiah).

On the assumption that complete utilization of (a) mud from the fishponds, (b) human excrement, and (c) mud and human excrement, can be accomplished as substitutes for external fertilizer input, the nitrogen balance of the each hamlet was estimated (Table 10). Reduction of nitrogen surplus in Mangunkerta will be the largest, where the potential of these local resources exceeds the external input of fertilizer. Reduction of nitrogen surplus in Galudra will be the smallest, and it will still have high value of nitrogen surplus, because of its large area and severe conditions in upland fields where nitrogen input is excessive. It is suggested that mere application of unused local resources is not enough to tackle the problem of nitrogen surplus in Galudra, and that there is a need for fundamental improvement in fertilizer management in upland fields as discussed in previous section.

In order to facilitate and promote the utilization of unused local resources, it is necessary to elucidate constraints on it, and effort to remove or defuse these constrains are essential. For instance, difficulty in handling the mud due to its heavy weight (average of ca. 240 kg per kg of nitrogen) seems to be the most significant constraint on the utilization of it. The approach from fishpond to arable land will be significant for facilitating the application of mud. Thus, optimal spatial land use arrangement should be discussed. Utilization of human excrement may face strong cultural constraints in Indonesia. If technological solutions, such as composting technology, are provided, these should be affordable and cost-effective.

3.5. Functional linkage between in upper and in lower parts of the watershed

A large surplus of nitrogen that has been calculated for the three hamlets, is expected to run off or leach out because of heavy rain (2,000-3,400 mm year^{-1}) and well-drained volcanic ash soil (Andosol) on the surface of lahar plateau (Tamura and Kitamura, 2001). This may lead to pollution of ground water and surface water. It is remarkable that

Galudra, the most upstream hamlet among the three, has recorded the highest nitrogen surplus primarily because of large nitrogen input to upland fields (Table 5), where market-oriented vegetables adapted to highland climate were intensively cultivated. Eutrophication of Cirata reservoir, into which the Cianjur–Cisokan river flows, might have been caused by such high N surplus, and lead to mass mortality of fish in the cage culture (Kurokura *et al.*, 2001).

Generally, wetland has a function of nitrogen removal by plant uptake and denitrification (Humenik *et al.*, 1999). The low nitrogen use efficiency of tropical rice field due to nitrogen loss by denitrification and NH_3 volatilization, and increasing nitrogen use efficiency is frequently discussed (e.g. De Datta, 1995). On the other hand, nitrogen removal in rice fields of Japan is seen as a water purification function that has been supported by several researches (e.g. Tabuchi *et al.*, 1996).

In the case of the Ciajur-Cisokan watershed area, rice fields in the lower catchment areas, such as Selajambe, can function as sites of nitrogen purification by plant uptake, denitrification, and NH_3 volatilization. This is in contrast to the situation in the upstream reaches, as exemplified by Galudra. Thus, an evaluation of ecological functional linkages between the upper and the lower reaches of a catchment is as important as functional evaluation of rural ecosystem at hamlet-scale. Landscape-scale studies should be carried out to quantify the potential of certain landscape elements to support high denitrification nitrogen losses, or to absorb significant amounts of nitrogen from other areas in the landscape in relation to concerns about N_2O emissions (Groffman, 1995).

4. Conclusions

Human activities have substantially influenced nitrogen cycle in most ecosystems at various spatial scales, making it difficult to separate natural aspects of nitrogen cycling from those induced by human perturbations. Artificial nitrogen flows estimated in this study would be playing overwhelmingly dominant role in nitrogen cycling of our study area in terms of quantity of flow. Moreover, this would indirectly influence the natural process of nitrogen flow. For instance, nitrogen input through fertilizer application generally accelerates nitrogen loss through natural process of nitrogen flows such as leaching, denitrification, NH3 volatilization, etc.

Application of our methods enabled estimation of artificial nitrogen flow at hamlet scale, indicating that rural ecosystems of the three hamlets have already been open systems with high dependency on the market, and that large nitrogen surplus of hamlet would outflow from the system through natural process of nitrogen. As local resources, livestock manure and crop residues have already been highly utilized as fertilizers. Utilization of unused local resources, mud from the fishponds and human excrement, could improve ecological and socio-economic sustainability of each hamlet. Nevertheless, Galudra will still have high nitrogen surplus after complete application of these unused local resources. Thus, it would be difficult to restructure the rural ecosystem to establish a closed and self-sustained system at hamlet scale under present condition, and therefore, enlargement of spatial scale is necessary to address the issue of sustainability of regional ecosystems in terms of nitrogen flow.

In addition, results of the study suggested a need for evaluation of ecological functional linkages between the upper and the lower catchment areas of the watershed. For instance, relationship between N surplus in the upland fields in the upper catchment area and water pollution, or nitrogen removal function of the rice fields in the lower catchment areas need detailed investigation. Although only “artificial” nitrogen flow was estimated in this study because of convenience and availability of the data, understanding of natural nitrogen flow process is essential to evaluate the ecological functions of the components of the watershed landscape. It is also necessary to enhance the precision of the data for estimation of nitrogen flow at hamlet scale.

The framework for a component model of nitrogen flow at the hamlet scale comprises components utilized by village residents in their daily life. It does not, however, include land use outside the hamlet, such as the vast tea plantation and the primary and secondary forests. In evaluating sustainability of the regional ecosystems, these land uses cannot be neglected. Hence, this framework is insufficient for evaluation of sustainability on a regional basis, and a larger spatial-scale framework will be required for future studies.

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Table 1
Processes and its magnitude of nitrogen flows

Process			Type[a]	Magnitude of nitrogen flows[b] (kg N $year^{-1}$ ha^{-1})
Inputs				
	Artificial	IN1	Mineral fertilizer	0 - 30 (95[c])
		IN2	Organic fertilizer	0 - 40
	Natural	IN3	Atmospheric deposition	0 - 10
		IN4	Biological N fixation	0 - 20
		IN5	Sedimentation	0 - 4
Outputs				
	Artificial	OUT1	Harvest products	0 - 80
		OUT2	Removed crop residues	0 - 20
	Natural	OUT3	Leaching	0 - 40
		OUT4	Gaseous losses	0 - 30
		OUT5	Erosion	0 - 40

[a] After Smaling (1993, cited in De Koning *et al.*, 1997)

[b] Summarized from Stroorvogel *et al.* (1993), Smaling *et al.* (1993), Jensen (1993), De Koning *et al.* (1997), Krogh (1997), and Mailly *et al.* (1997)

[C] Average mineral fertilizer input to arable lands in Indonesia in 2000 based on the data from FAOSTAT (URL: http://apps.fao.org)

Table 2
General information on villages including the study hamlets in the Cianjur-Cisokan watershed area, West Java, Indonesia

	Galudra	Mangunkerta	Selajambe
Elevation	ca. 1,200m	ca. 950m	ca. 300m
Area (ha)	510	205	388
Population	3,512	5,740	6,232
Population density （ha^{-1}）	6.9	28.0	16.1
Dominant land	upland field	upland field paddy field	paddy field
Main source of cash income	agriculture	agricultural labor non-agricultural activities	agricultural labor non-agricultural activities

Table 3
Contents of the questionnaire

Family
- 1. family name
- 2. member
  (name, age, occupation)

Biological production
- 3. status of land ownership
  (land use type, area (m^2))

Home garden
- 4. crop, yied, purpose,
  treatment of crop residue

Mixed garden
- 5. crop, yield, purpose,
  treatment of crop residue

Paddy field
- 6. cropping calendar
- 7. crop, yield, purpose,
  treatment of crop residue

Upland field
- 8. cropping calendar
- 9. crop, yield, purpose,
  treatment of crop residue

Forest garden
- 10. crop, yield calendar

Livestock
- 11. kind, number, purpose

Fishpond
- 12. kind, yield, purpose

Fertilizer

Organic fertilizer
- 13. utilization of livestock excrement
  (kind, place, pecentage utilization, quantity)
- 14. utilization of human excrement
- 16. treatment of ground litter of home garden
- 17. treatment of kitchen garbage, place to dum
- 18. treatment of mud in the fishponds
  (frequency of cleaning, place to dump)

Chemical fertilizer
- 19. place to use, kind, quantity

Fodder
- 20. kind, source, purpose, quantity

Food Supply
- 21. Supply from market and arable land
  (kind, quantity)

Consumption
- 22. Consumption of the family

Fuel
- 23. kind, source, quantity

Table 4
Status of land ownership of sampled households in the three hamlets in Cianjur-Cisokan watershed, West Java

Village		Home garden									
		Total	House	Open space	Fishpond	Livestock shelter	Mixed garden	Paddy field	Upland field	Forest garden	Total area (m^2)
Galudra	Percentage of owner household[a] (%)	100%			33%	25%	-	-	72%	0%	
	Average area (m^2)	184	66	114	5.0	6.8	-	-	4,360	0	
	Total area (m^2)	11,019	3,949	6,868	99	102	-	-	187,500	0	198,519
	(%)	6%					-	-	94%	0%	100%
Mangunkerta	Percentage of owner household (%)	100%			45%	67%	7%	18%	20%	3%	
	Average area (m^2)	188	58	123	8.5	5.5	950	1,336	866	2,400	
	Total area (m^2)	11,274	3,471	7,356	229	219	3,800	14,700	10,388	4,800	44,962
	(%)	25%					8%	33%	23%	11%	100%
Selajambe	Percentage of owner household (%)	100%			10%	55%	10%	38%	-	3%	
	Average area (m^2)	192	68	119	42.5	3.2	550	3,465	-	6,700	
	Total area (m^2)	11,518	4,061	7,154	255	48	3,300	79,700	-	13,400	107,918
	(%)	11%					3%	74%	-	12%	100%

[a] It indicates percentage of the households that own the land which is cultivated or utilized by themselves. Households that cultivate or utilize leased land is also included here. Households that rent their land to other people is not included.

Table 5

Total nitrogen balance in the three hamlets of Cianjur-Cisokan watershed area, West Java

	Compartment	External inflow ($kg\ N\ year^{-1}$)	External outflow ($kg\ N\ year^{-1}$)	External nitrogen balance ($kg\ N\ year^{-1}$)
Galudra	Home garden	226	27	200
	Mixed garden	0	0	0
	Forest garden	0	107	-107
	Upland field	5,244	888	4,357
	Livestock	54	37	17
	Human	837	0	837
	Total	6,362	1,058	5,304
	(ha^{-1})	**320**	**53**	**267**
Mangunkerta	Home garden	63	4	59
	Mixed garden	48	41	6
	Forest garden	0	38	-38
	Upland field	101	9	92
	Paddy field	222	42	179
	Livestock	111	73	38
	Human	740	0	740
	Total	1,284	208	1,076
	(ha^{-1})	**286**	**46**	**239**
Selajambe	Home garden	0	4	-4
	Mixed garden	0	74	-74
	Forest garden	0	59	-59
	Upland field	0	0	0
	Paddy field	2,311	1,983	328
	Livestock	238	23	214
	Human	528	0	528
	Total	3,077	2,143	934
	(ha^{-1})	**285**	**199**	**87**

Table 6
Nitrogen input through fertilizer in the three hamlets of Ciajur-Cisokan watershed, West Java (kg N $year^{-1}$ ha^{-1})

		Chemical fertilizer (kg N $year^{-1}$ ha^{-1})	Manure (kg N $year^{-1}$ ha^{-1})	Total (kg N $year^{-1}$ ha^{-1})
Galudra	Home garden	205	0	205
	Upland field	219	102	321
Mangunkerta	Home garden	56	19	74
	Mixed garden	125	34	159
	Upland field	98	106	204
	Paddy field	151	52	203
Selajambe	Home garden	0	0	0
	Mixed garden	0	0	0
	Paddy field	290	9	299

Table 7
Nitrogen loading indices of the three hamlets in Ciajur-Cisokan watershed, West Java

	Edible nitrogen output from arable land (kg N $year^{-1}ha^{-1}$)	Edible energy output from arable land (1,000 GJ $year^{-1}ha^{-1}$)	NSENO[a]	NSEEO[b] (kg N 1,000 GJ^{-1})
Galudra	37	24	7.2	10.9
Mangunkerta	15	18.6	16.5	12.9
Selajambe	175	124.1	0.5	0.7

[a] (Nitrogen surplus per edible nitrogen output) = (Nitrogen surplus)/(Edible energy output from arable lan

[b] (Nitrogen surplus per edible energy) = (Nitorgen surplus)/(Edible energy output from arable land)

Table 8
Price and weight of fertilizers per unit of nitrogen

	N content	Price		Weight
	(%)	(Rp*/kg fertilizer)	(Rp/ kg N)	(kg fertilizer/kg N)
Urea	46.0%	1,300	2,826	2.2
Ammonium sulfate	21.0%	1,400	6,667	4.8
NPK	14.0%	3,500	25,000	7.1
Chicken manure	3.3%	200	6,098	30.5

* Rp = Indonesian Rupiah (US$ 1 = 10,000 Rp)

Table 9
Percentage of utilization of animal excrement as fertilizer

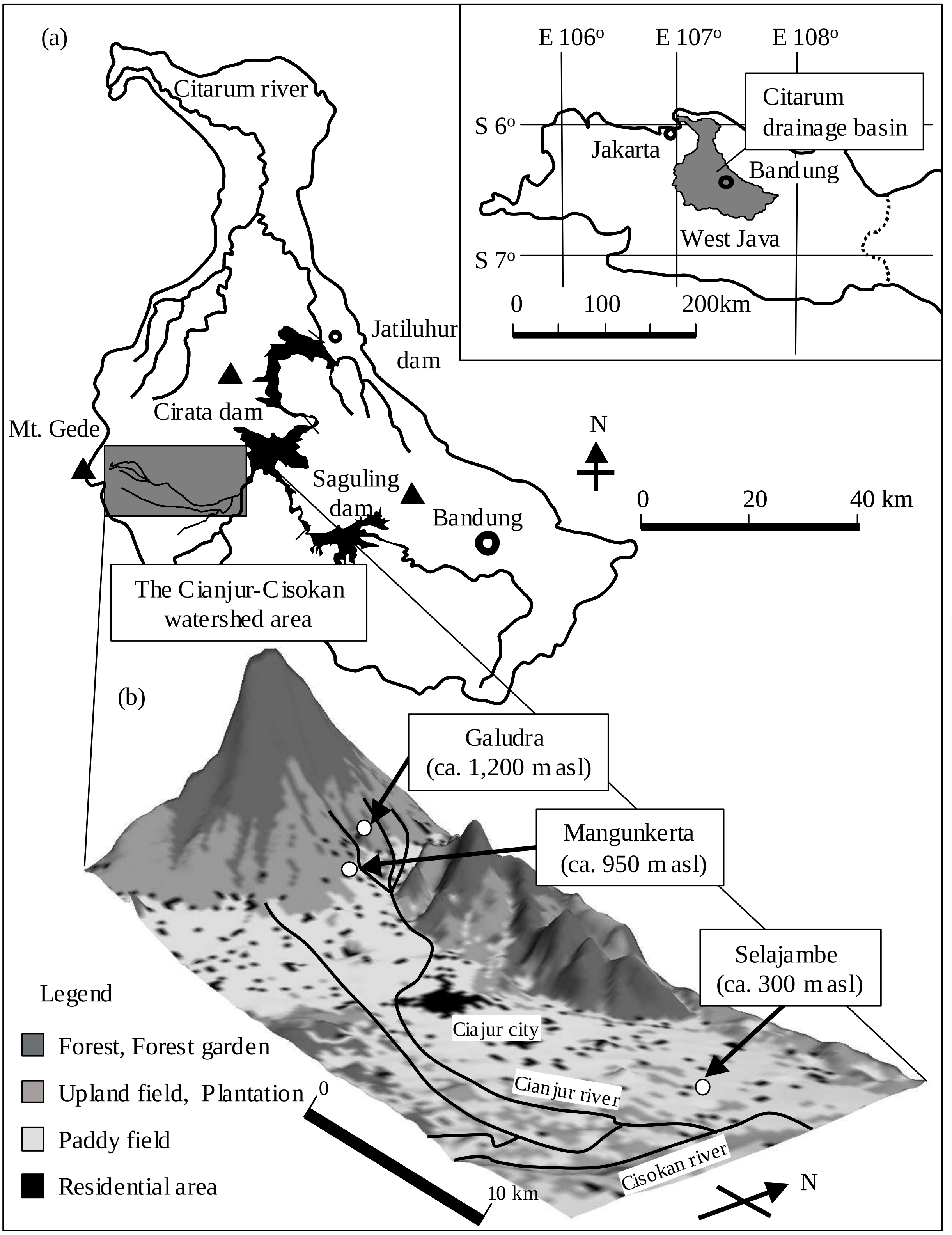
	Galudara	Mangunkerta	Selajambe
Chicken	42.0%	65.1%	26.9%
Sheep	100.0%	78.5%	27.3%
Goat	-	94.3%	-
Rabbit	100.0%	74.5%	-

Table 10

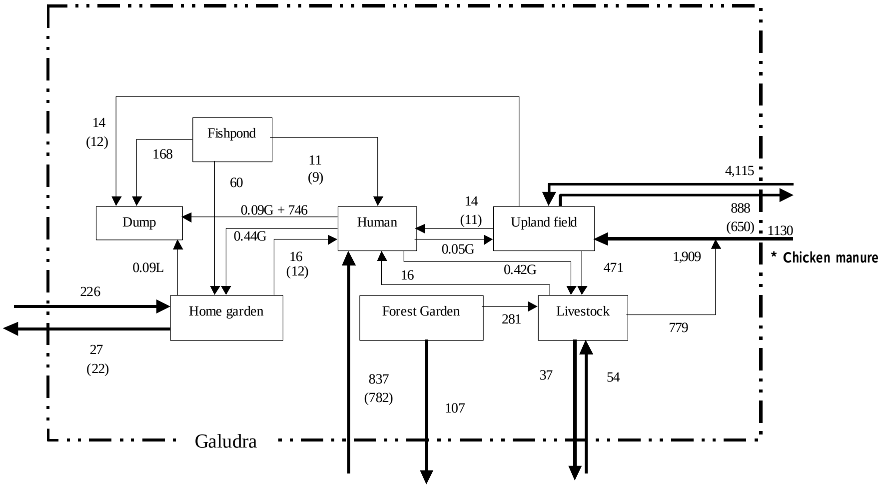
Nitrogen balance of the three hamlets according to utilization of unused local resources (kg N year-1 ha-1)

	Galudra	Mangukerta	Selajambe
(a) Present State	267	239	87
(b) Complete utilization of mud	259 (8)[a]	210 (29)	72 (15)
(c) Complete utilization of human excrement	230 (38)	143 (96)	30 (57)
(d) Complete utilization of mud and human	219 (49)	143 (96)	15 (71)

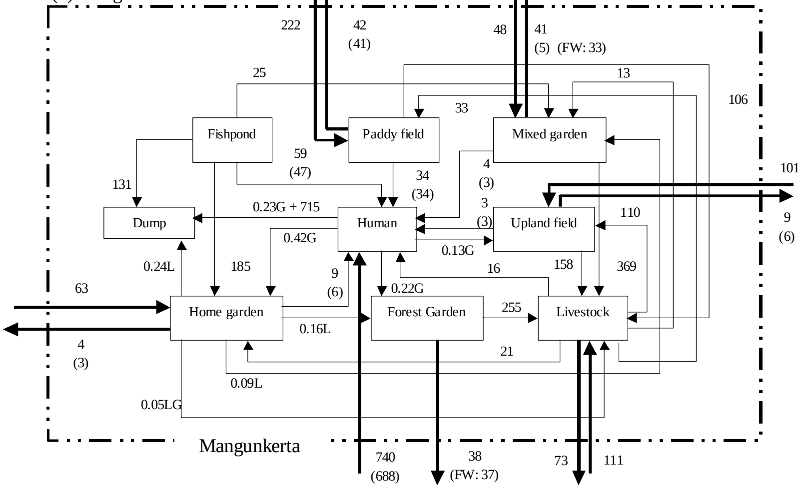
[a] Reduction of nitrogen surplus (kg N year^{-1} ha^{-1})compared with present state


(a)
E 106°
E 107°
E 108°
S 6°
S 7°
Citarum drainage basin
Jakarta
Bandung
West Java
0
100
200km
Citarum river
Jatiluhur dam
Cirata dam
Mt. Gede
Saguling dam
Bandung
N
0
20
40 km
The Cianjur-Cisokan watershed area
(b)
Galudra (ca. 1,200 m asl)
Mangunkerta (ca. 950 m asl)
Selajambe (ca. 300 m asl)
Ciajur city
Cianjur river
Cisokan river
0
10 km
N
Legend
Forest, Forest garden
Upland field, Plantation
Paddy field
Residential area

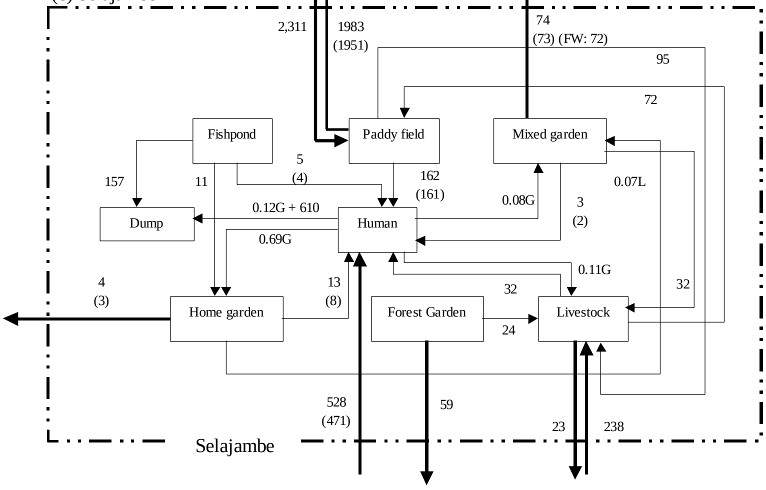
(a) Galudra



(b) Mangunkerta



(c) Selajambe



[a] Values inside parentheses indicate nitrogen in edible portion of the crops.

[b] "G" and "L" means garbage from kitchen and ground litter of home garden, respectiverly. For instance, "0.44G" attached to dotted arrow from compartment "Man" to "Home garden" in Fig. 4 (a) indicates 44% of garbage is dumped to home garden.

[c] "FW" indicates the nitrogen flow due to burning fuel wood.

Figure captions

Fig. 1. Location of the Cianjur-Cisokan watershed area (a), and its landscape structure including location of the study hamlets (b).

Fig. 2. Component model of nitrogen flow (kg N year^{-1}) of (a) Galudra, (b) Mangunkerta, and (c) Selajambe in the Cianjur-Cisokan watershed area, West Java.