Red Soil Runoff from the Miyara River, and an Environmental Problem on Ishigaki Island

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ABSTRACT

A large volume of sediments has entered the coastal areas of the Ryukyu (Nansei) Islands, particularly Okinawa Island, as a result of large-scale agricultural land preparation and development projects. This has resulted in damage to the valuable ecosystem of corrals and seaweed beds and to the coastal landscape and fisheries. A water-quality survey was conducted over a four-year period at the Miyara River to measure suspended solids, nitrogen and other elements, and the river flow rate, so as to provide important information for planning load reduction measures and management methodologies for the catchment area. The volume of red soil and the total nitrogen loads transported by the rivers were determined, taking into account the frequent soil runoff and increases in nitrogen emissions associated with rainfall. The volume of fertilizer input was also estimated from existing data.

Keywords: red soil flow, flow observation, L-Q equation, SS, nitrogen

1. Introduction

A large number of public works projects were carried out in the islands of Okinawa, centering on the main island of Okinawa, following the return of the islands to Japan from the United States of America. In relation to agricultural land development and field development, large-scale projects involving the elimination of slopes were implemented to create farmland suitable for mechanized farming. One of the widely used methods for turning slopes into farmland is field reclamation at improved slope, which involves leveling the vertically irregular topography of slopes by cutting and filling to create flat land suitable for mechanized farming.

Since this method results in relocation of large amounts of soil and the extensive exposure of immature soil, various types of damage, such as soil erosion by heavy rainfall and slope failure, often occur for a few years following the completion of the work. These types of damage caused widespread devastation to large-scale land-improvement projects in the Okinawa islands, including the main island of Okinawa and Ishigaki Island. The soil of the islands of Okinawa and Nansei is categorized as "red-yellow soil" (*Kunigami Maaji*), which is highly susceptible to structural collapse as it is scattered by raindrops and rainwater. Land in tropical areas typically has thin layers of humus and is subject to decomposition, ablation, and eluviation of organic materials once the covering vegetation is removed; this is likely to create unstable soil conditions as a result of the loss of the water-retention or drainage capacity of soil humus.

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2. Monitoring of Flow Rate and Water Quality in the River Basins

Soil runoff from farmland is always associated with a deterioration of the quality of river waters. On islands, where there is less flatland and therefore more farming on hills and slopes, there is an intimate relationship between soil runoff and river water quality. We focused on the main rivers along which agriculture and stock-raising are actively pursued. We made long-term hydrological measurements, such as flow-rate measurements and we monitored water-quality parameters, such as the turbidity and suspended solids (SS), to calculate rough values of water-quality loads associated with rainfall.

(1) Observation Points and Methodology

We had six fixed observation points along the Miyara River basin (Hegina Weir, Kawahara Bridge, Futamata Weir, Shinko Bridge, Nakamizu Bridge, and Todoroki Bridge in Fig. 1). A water gauge and an automatic continuous water sampler were installed at the Hegina Bridge point in the downstream area of the Miraya River. The water gauge was kept permanently operational, whereas the water sampler was activated mainly during rainfall or flood. Sample containers filled with water samples were taken back to the laboratory for analysis. In addition to the Miyara River watershed, the other river basin of the Todoroki River was chosen for comparison of the measurement results. The properties of the sampled water that were measured were the pH, electrical conductivity (EC), turbidity, and water level in the river. Samples taken back to the laboratory were analyzed for total nitrogen (T-N), total phosphorus (T-P), SS, etc.

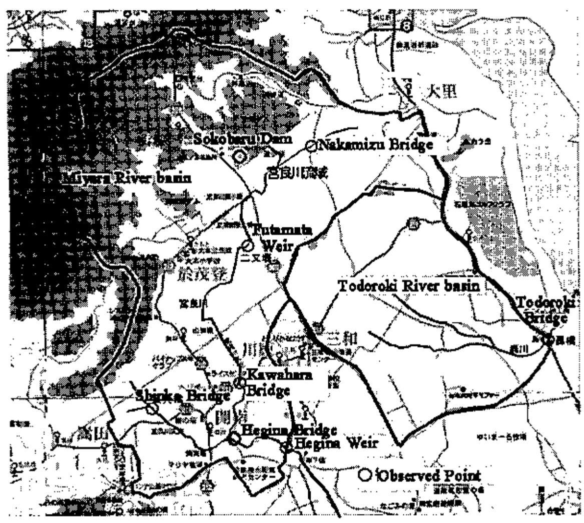

Fig. 1. Basins of Miyara River and Todoroki River

(2) Land Use

The watershed area of the Miyara River is 27.34 km^2 and it is mainly composed of the catchment areas of the Maesato Dam and the Sokobaru Dam (forests) covering an area of 11.15 km^2 (36%), paddy fields covering an area of about 1.0 km^2 (3.7%), and upland fields (sugar cane, pineapple, pasture, etc.) covering about 8.23 km^2 (30%). The area of the Todoroki River watershed is 13.23 km^2, consisting of 4.94 km^2 of forests and residential area (37%), 0.45 km^2 of paddy fields (3.4%), and 3.88 km^2 of upland fields (sugar cane, pineapple, pasture, etc.) (29%).

3. Monthly Observation Results

According to the Red Soil Prevention Ordinance of the Okinawa Prefecture, the SS level of the river water should be below 200 mg/L. Observation of the river basin for over a year allowed us to identify changes, periodicity, and long-term trends. It is not surprising to note that the results, as shown in Fig. 2, often exceeded the limit values stipulated in the ordinance.

In terms of the relationship between turbidity and the measurement points, the level of turbidity increased (as shown in logarithmic representation) with increasing daily rainfall on the sampling days; such results for rainy days showed an increase of about 100 times compared with those on days without rain. This is probably the result of runoff of soil in a suspended state from the upland fields in the river basin (Fig. 2). Particularly high values were observed at the Shinko Bridge point, located in farmland in the upstream area of the Miyara River, and the Todoroki Bridge point, along the Todoroki River, a river surrounded by agricultural land.

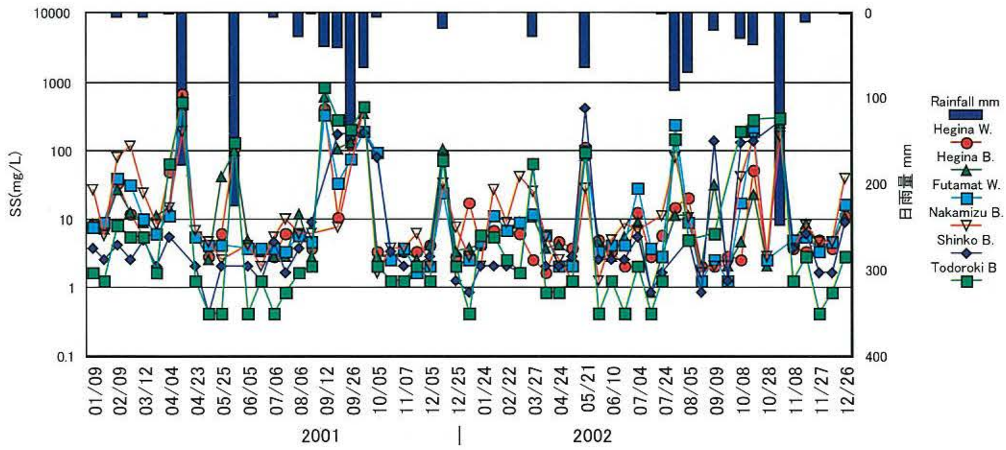

Fig. 2. SS(suspended solid) values at each observation point of the basins at 2001-2002

4. Annual SS at Two Points

SS measurements at two of the seven observation points, the Hegina Bridge point and Todoroki Bridge point, located in the downstream areas, are shown by year in Fig. 3. The values increased during years with many rainy days and typhoons, and remained low in years with less rainfall. The average SS values for those two points were less than the regulatory limit of 200 mg/L in red soil SS, but the maximum values reached almost 1000 mg/L. The annual highs showed a decline for the past four years, but as it is uncertain whether the SS will continue to decline in the future, it will still be necessary to continue soil-preservation efforts on farmland. The river water under the Todoroki Bridge in normal times is clear, in stark contrast to the dark water observed during rainfall.

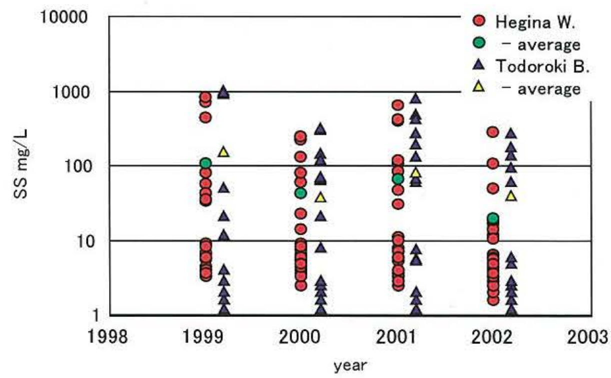

Fig. 3. SS values by the year of 2 observation points

5. Changes of SS and T-N from the Estuary to the Upriver Point

Fig. 4 shows measured values for the observation points along the Miyara River, going upstream from the estuary. The SS value at the Sokobaru Dam point is low, as the dam stores runoff water from the mountainous area of Mount Omotodake and the sediments that flow into the river settle in the bottom of the dam reservoir. A little way downstream of the dam, higher SS values are found, but no decline in SS is observed on going further downstream. Once the SS value rises, the elevated value continues down to the sea.

Fig. 5 shows the values of the nitrogen content at each observation point. The nitrogen concentration at the point of the Sokobaru Dam, where water flows down from sources in the mountains and settles, is the lowest, and the value rises in the direction of the estuary. The value at the Shinko Bridge point, located in the tributary area, is excessively high because of its proximity to pasture and cow barns. The value during rainfall is particularly high at this observation point. The nitrogen concentration along the main river below the point of confluence with this tributary is lower than that at the Shinko Bridge point as a result of dilution of the water.

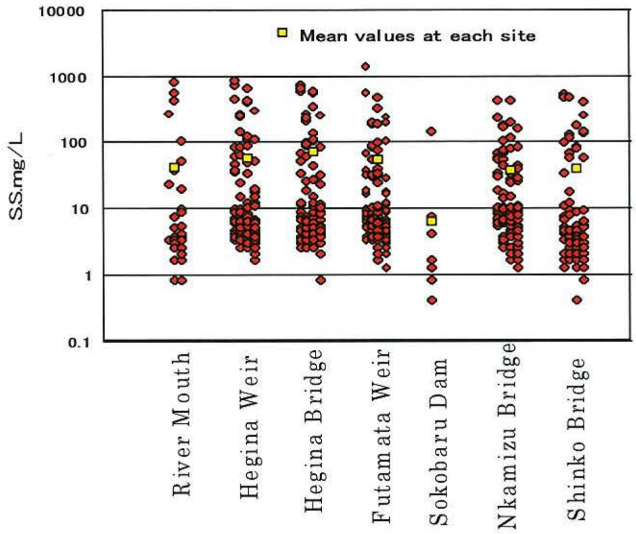

Fig. 4. SS values from river mouth to the upper reaches observation point

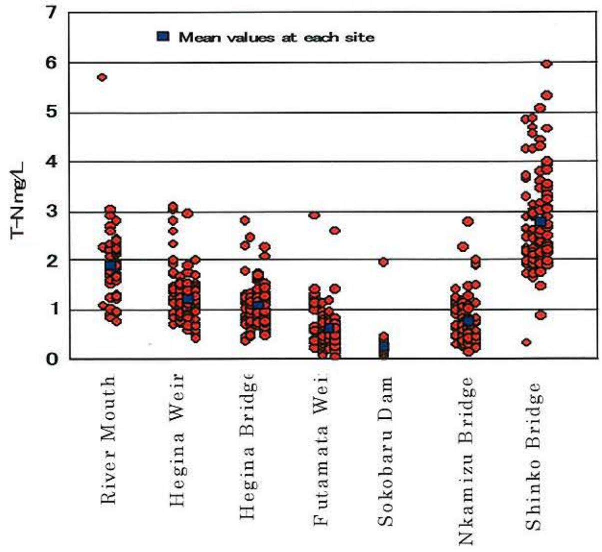

Fig. 5. T-N values from river mouth to the upper reaches observation point

6. Overflow Volume of the Miyara River

The flow rate of the river water at the Hegina Weir and Hegina Bridge points was also measured at designated observation times and during rainfall by means of an electromagnetic flowmeter. As a water gauge was also installed at the Hegina Bridge point, we were able to chart the water level-flow rate curve, which we refer to as the "first curve." At the Hegina Weir, river water is pumped up for distribution to other areas as irrigation water. The water level decreases, except on rainy days, because of the pumping of water. The pump operation/water level-flow rate curve is a chart that represents the relationship between the pump discharge and the water level changes. Those two water level-flow rate curves, parts of which are shown in Fig. 6, were used to calculate the river runoff. This Figure also shows the amount of rainfall and the water levels. The total annual flow rate, calculated as above, between July 2000 and June 2001 is shown in Table 1: for this one-year record, the rainfall was 2601 mm whereas the overflow was 1955 mm.

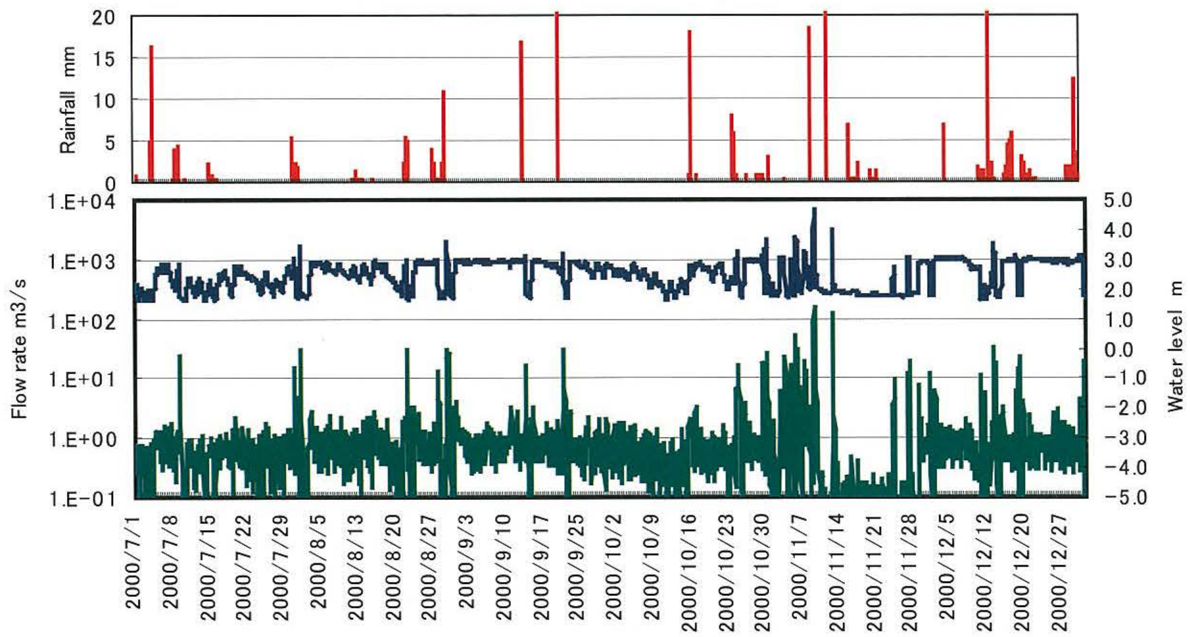

Fig. 6. Relationships among rainfall, water level and river flow rate

7. Relationship between SS, T-N and Flow Rate

The annual soil runoff and the loads of nitrogen and phosphorus are calculated by multiplying the river flow rate by the concentration of each element. Because the concentration values are not continuously generated, an equation is necessary for estimating the annual loads from the discontinuous measurements. In this case, regression equations for flow rates and loads (observation values) were used to estimate the loads.

The regression equations (LQ equations) of the flow rate and loads are shown in Fig. 7 and Fig. 8. SS values are represented in two equations, taking into account the rainfall intensity. Some of the calculations of the loads using those regression equations are shown in Fig. 6. It is shown that the loads fluctuate with large changes in the flow rate.

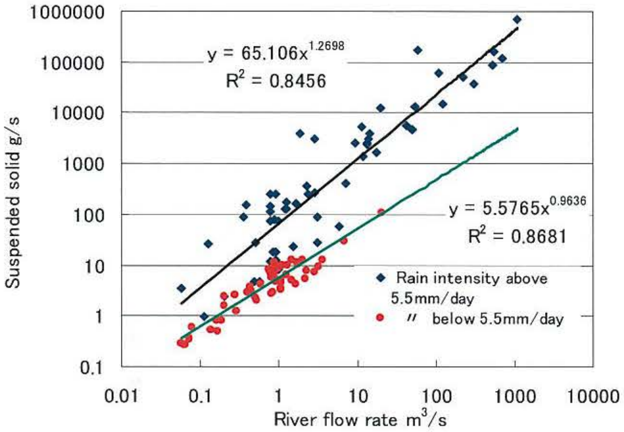

Fig. 7. The relationship flow rate and SS load

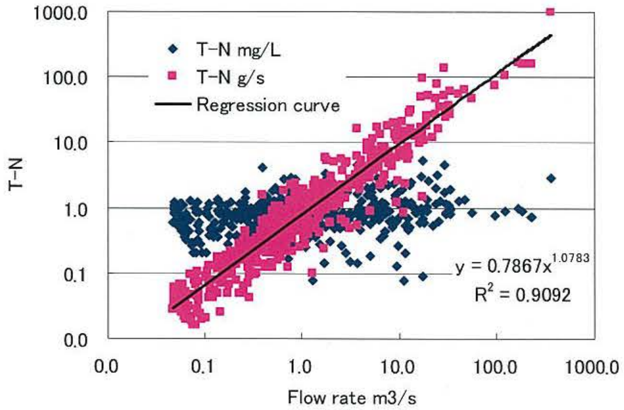

Fig. 8. The relationship flow rate and T-N load

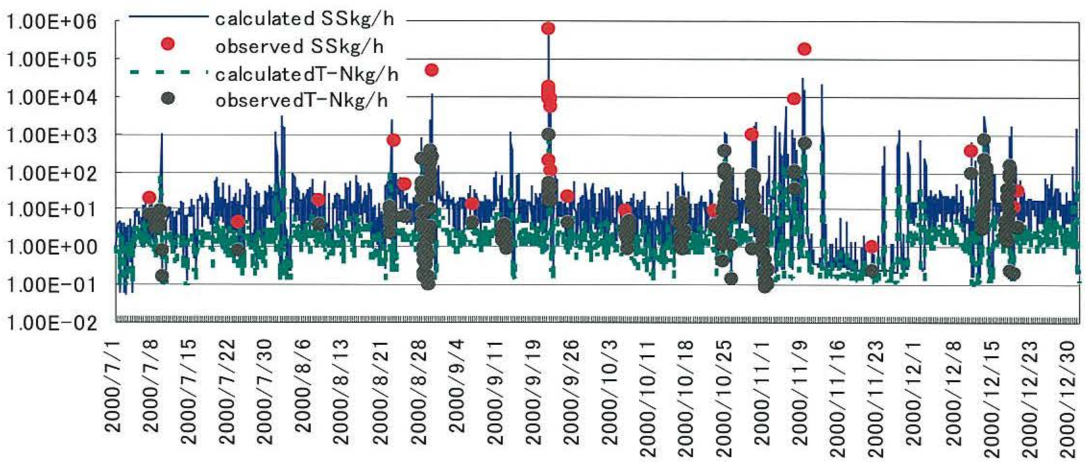

Fig. 9. Relationships among SS load, T-N load and time

8. Annual Material Balances for SS, T-N, and T-P

The annual loads of SS, nitrogen, and phosphorus carried to the sea are 1882 metric tons, 68 metric tons, and 7 metric tons, respectively. Assuming that the suspended solids are all made up of soil particles and that the specific gravity of river basin subsoil is 1.3, by dividing the volume of particles by the total area of fields, the average depth of soil erosion can be estimated to be 0.2 mm (Table 1).

Annual nitrogen and phosphorus inputs from domestic livestock excreta and fertilizers were calculated on the basis of the Agricultural and Forestry Statistics for Ishigaki City to be 276 metric tons and 113 metric tons, respectively (Table 2). The proportion of these inputs carried to the sea are therefore calculated to be

25% for nitrogen and 6% for phosphorus, respectively, which indicates that the outflow of phosphorus is much smaller than that of nitrogen. It is probable that much of the phosphorus is absorbed by soil or plants.

Table. 1. Rainfall, river flow, suspended solids, Total N outflow and Total P from July 2000 to Jun 2001

Rainfall (mm)	River flow (mm)	Suspended solid (ton)	T-N outflow volume (ton)	T-P outflow volume (ton)
2601	1995	1882	68	7

Table. 2. Total amounts of nitrogen and phosphorus in agriculture fertilizer and from livestock excretions in one year

	T-N (ton/year)	T-P (ton/year)
Livestock excretions*1	100	12
Agriculture fertilizer *2	176	101
Total amount	276	113

*1 It presumes based on the livestock numbers 2120 bred in a basin. *2 From the planted area according to crop kind, and the amount of their standard fertilization to presumption

9. Conclusion

Red soil runoff, a problem for the Okinawa prefecture, is an environmental pollutant originating from development and preparation of farmland. It has caused a heavy accumulation of red soil in coastal areas of the island, particularly near shallows where corrals grow, leading to destruction of corrals and other major colonies of marine life. We investigated and measured the amount of red soil transported by rivers, the soil runoff associated with the increased water overflow due to rainfall, and increased loads of nitrogen and phosphorus during four years. The results, although incomplete, revealed the current status of soil runoff and its associated problems.

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