Estimation of groundwater discharge in a sandy beach; An example of Fukiagehama, Kagoshima Prefecture, Japan

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INTRODUCTION

It is recognized that links among forests, rivers and sea are important, because biological and fisheries production in the coastal zone is influenced by land-sea interaction. There are several nutrient supply systems in the coastal zone. River runoff, the most dominant nutrient supply system, has been evaluated by many previous studies. In addition, submarine groundwater discharge (SGD) has recently been considered as an important source of dissolved material to the coastal zone. For example, Johannes (1980) shows that SGD supplies several times as much nitrate volume as river runoff. However, the nutrient supply mechanisms in sandy beach ecosystem are not yet fully understood. Thus, it is necessary to quantitatively evaluate freshwater discharge and nutrient supply in a sandy beach ecosystem. This study reveals the estimated flow rate and volume of groundwater discharge in Fukiagehama, Kagoshima Prefecture, Japan.

RESEARCH PROCEDURES

Study area:

Fukiagehama is located on the western coast of Kagoshima Prefecture, Kyushu, Japan (Figure1). The sandy beach is known as a spawning ground for loggerhead turtles, and the surf zone is significant habitat for various juvenile fishes, including important species for fisheries(e.g. Nakane et al. 2011). Seven rivers flow into Fukiagehama, of which the Manose river (watershed basin area: 372.3 km^2) is the largest, followed by the Kamino river (98.8 km^2) and the Nagayoshi river (50.4 km^2). The rivers flowing into this watershed basin are mostly small rivers. Figure2 shows the subsurface geology of Fukiagehama basin. Pyrcoclastic flow deposits which are called SHIRASU, tend to occupy a large ratio of the subsurface geology.

Methods:

A water budget method was applied to estimate the freshwater discharge rate and volume in the Fukiagehama basin (Figure3). The water budget equation is expressed as

$$P = R + G + E + \Delta S \tag{1}$$

where P is the precipitation, R is the river flow, G is the groundwater flow, E is the Evapotranspiration, ΔS is the change in water storage. However, this study does not consider the change in water storage, because this change can be disregarded for cases that consider longterm water budget, as is the case in this study, which was performed to determine the annual water budget. Thus, the water budget equation in this project is as follows;

$$P = R + G + E. \tag{2}$$

The average precipitation in the basin was calculated by using AMeDAS precipitation data from the Japan Meteorological Agency after conducting Thissen sub-

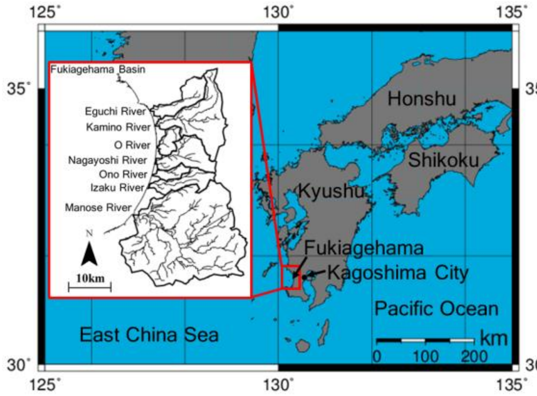


Figure 1 Project area

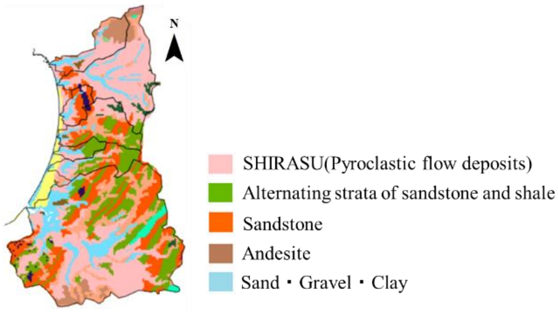


Figure 2 Subsurface geology of Fukiagehama Basin

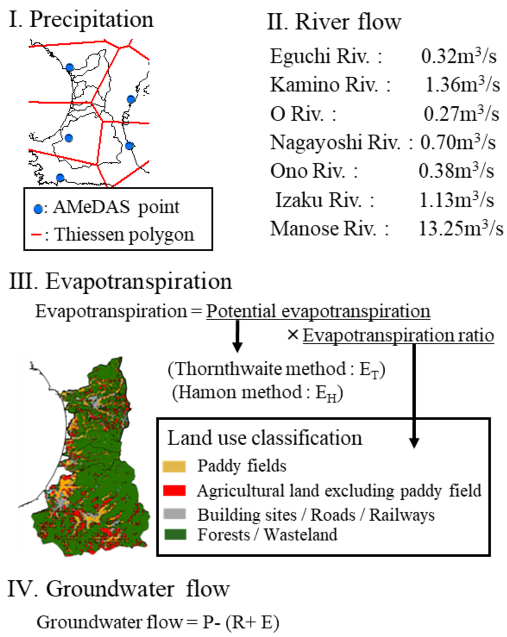


Figure 3 Outline of water budget method

division of Fukiagehama basin. The river flow data observed by Kagoshima Prefecture were applied. The evapotranspiration amount was calculated by multiplying potential evapotranspiration amount and evapotranspiration ratio. The potential evapotranspiration amount was estimated by using Thornthwaite method and Hamon method, which can easily estimate the potential evapotranspiration amount from the monthly average temperature. The Thornthwaite method is expressed as equation (3).

$$E_T = 16D_0\,(10T/I)^a \tag{3}$$

where $I = \Sigma(T/5)^{1.514}$, $a = (492, 390 + 17, 920I - 77.1I^{2} + 0.675I^{3}) \times 10^{-6}$, E_T is the potential evapotranspiration amount (mm/month), D_0 is the monthly average number of hours of possible sunshine, and T is the monthly average temperature (°C). The Hamon method is expressed in equation (4) as follows;

$$E_H = 0.14D_0^{2}\,Pt. \tag{4}$$

where E_H is the potential evapotranspiration amount (mm/month), D_0 is the monthly average number of hours of possible sunshine, Pt is the absolute saturation humidity (g/m^3) per monthly average temperature(°C). The amount of evapotranspiration was estimated by multiplying the evapotranspiration ratio as a coefficient by the potential evapotranspiration amounts, which were calculated using equations (3) and (4). The evapotranspiration ratio was estimated by conducting land use classification by using ArcGIS 10.0 (ESRI). For land use classifications, the percentages of land use area for each watershed basin were calculated based on the subdivided mesh data for land use from National Land Numerical Information using. For convenience, the land use classifications were reclassified into "paddy fields," "Agricultural land excluding paddy field," "building sites, roads, and railways," and "forests and wasteland". The evapotranspiration ratios that were used herein are listed in Table1. Finally, the estimated evapotranspiration amounts were calculated by multiplying the potential evapotranspiration amounts by the evapotranspiration ratio of each watershed basin area. Ultimately, the precipitation amount, river flow, and evapotranspiration amount can be calculated, equation (2) can be transformed into

$$G = P - (R + E). \tag{2'}$$

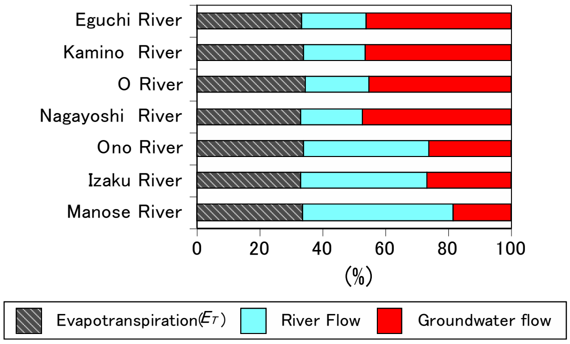
Consequently, the groundwater flow can be calculated using the transformed equation.

ESTIMATION

The average precipitation in the basin is approximately 2,200mm, and is greater than the Japan national annual average rainfall. It is seen based on the average value of the basin that the river flow is 29.7%, the groundwater flow is 36.6 to 37.8% of the total amount of precipitation for each estimation, and the rest is evaporated(Figure4). Therefore, the river flow is 44% and the groundwater flow is 55.3% to 56% of the total runoff. The estimated quantity of groundwater flow can be as much as 4.0×10^8 m^3/year (12.7m^3/s). This estimated volume is nearly the same volume of river flow in Manose river (13.3m^3/s), which is the greatest river in Fukiagehama basin. Large differences in the precipitation and evapotranspiration in each watershed basin of Fukiagehama did not exist. Therefore, the groundwater flow was thought to vary based on the impact of factors including, the area of the watershed basin and geological conditions. Fukiagehama watershed basin is located on a

Table 1 Evapotranspiration ratio

Land use classification	Jan.	Feb.	Mar.	Apr.	May	Jun.
Paddy fields	0.45	0.45	0.55	0.60	1.00	1.05
Building sites/Roads /Railways	0.45	0.45	0.55	0.60	0.65	0.70
Forests/Wasteland	0.90	0.90	0.70	0.50	0.60	0.80
Agricultural land excluding paddy field	0.85	0.75	0.80	1.65	0.70	0.75
Land use classification	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Paddy fields	1.25	1.30	1.30	1.20	0.70	0.55
Building sites/Roads /Railways	0.80	0.85	0.85	0.80	0.65	0.55
Forests/Wasteland	0.80	0.80	0.80	0.90	1.00	0.90
Agricultural land excluding paddy field	0.70	0.75	0.90	1.00	1.00	1.00



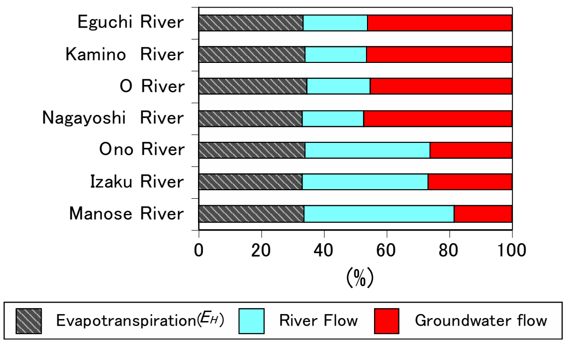


Figure 4 Percentages of evapotranspiration amount, river flow, and groundwater flow (Top image shows estimates using E_T and bottom image shows estimates using E_H)

volcanic flow plateau, particularly represented by SHIRASU, and therefore, the groundwater amount considerably varies depending on the geological features. It is likely that if there is a high percentage of SHIRASU, which is porous and highly permeable, then both the influence of surface geology and the amount of groundwater will be high.

CONCLUSIONS

It is clarified that quantity of groundwater can be as large as 4.0×10^8 m^3/year due to the large amount of precipitation and soil condition(much volcanic debris known as SHIRASU) for which permeability is high in general. Even though it is a macroscopic estimation using GIS, the groundwater flow is also important as a nutrient supply mechanism in the Fukiagehama basin.

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