A cross comparison of hydrological similarity and geological similarity for the sub-catchments within Natori river basin

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1. INTRODUCTION

People have long recognized the important role of surface topography in hydrology (eg. Horton, 1945). Topography provides information about uplift, weathering and erosion as well as their interactions, and therefore also provided information about the past morphological development of the landscape. In addition, it provides a strong binding force for future hydrology and landform changes, and for hydrology, it is a key driving force and control force related to runoff generation and other hydrological processes. This understanding of the past, present, and future effects of topography is undoubtedly one of the reasons why almost all key landscape entities in hydrology (such as watershed boundaries, hillsides and river networks) are derived from the topographic properties of the land surface. To support this, the digital elevation model (DEM) has a fairly high resolution globally, helping to promote the increasing popularity of spatially clear hydrological models.

It is therefore no surprise that hydrology does not suffer from a lack of models or indices linking geomorphic properties of a landscape with its hydrological functioning. The most popular approach is arguably the topographic wetness index (TWI). As a function of the local slope with the upslope contributing area per contour length, the TWI was originally developed to classify areas of similar functioning within a catchment and has been applied and tested in numerous studies.

However, other indices have also been proposed for linking land-surface topography with its runoff response. Hjerdt et al. (2004) developed the “downslope topographic wetness index” (also called the tanβ index) that reflects the local hydraulic gradient in the case that flow is exclusively driven by gravity and under the assumptions of a fixed drop in elevation. They claimed that this index represents groundwater level gradients in a manner that is superior to the classical TWI approach and showed it to be less sensitive to the quality of the DEM. An approach that has recently gained considerable attention is the “height above the nearest drainage” index (HAND). This approach assumes that water follows the steepest descent along the surface topography, and, based on these drainage paths, the corresponding elevation of each raster cell above the nearest corresponding river cell is estimated. HAND has been successfully applied and tested in numerous studies in a wide range of different landscapes.

The above-mentioned studies highlight the large potential of the topographic index and its relevance for hydrological research. From a theoretical point of view, topographic index like DEM reflects the gravitational potential energy of a given unit weight of water with the reference level set to the elevation of the nearest corresponding river. In this study, in order to represent this information in more detailed way, we will use 2 major histogram indexes: the histogram of slopes and the histogram of the distances to rivers, as the major topographic indexes. A distributed hydrological model was used to calculate the outflow and 3 hydrological indexes were used to measure the similarity. The similarity matrix of both geo-features and hydro features will be made to analyze how geo-feature can affect hydrological performance.

2. MATERIAL AND METHOD

2.1 Study site and description

The study area is Natori River basin which is located in central Miyagi prefecture, in the Tohoku region of Japan. The river's basin is 939 km2 and has two primary reservoirs. The river's length is 55 km, and its tributaries are the Hirose, Masuda and Goishi Rivers. The river's flow is the greatest during the snow melt season from March to April, the rainy season from June to July and during the typhoon season from September to October. The entire basin was divided into totally 83 sub-catchments. Those sub-catchments form the basic unit of similarity analysis in this sduty. Fig.1 had showed the river basin and its sub-catchemnts.

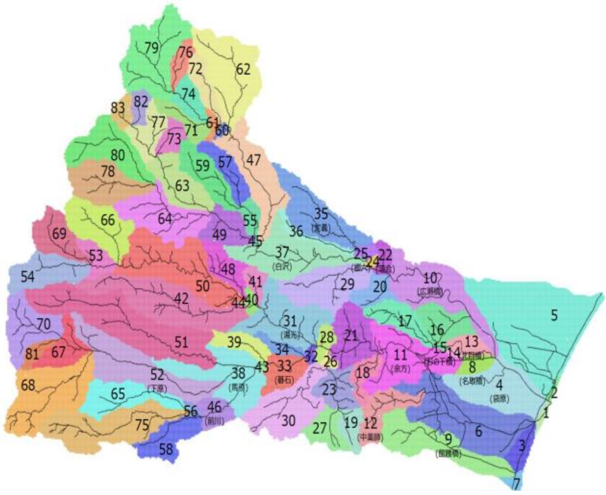

Fig. 1. The study area and the divided 83 sub-catchments.

2.2 Analysis methods

Topographic data used in this study is DEM data set and river maps of the study area with 40m resolution. These data were processed and generated 2 kinds of histogram data that can describe the features of each sub-catchments: the histogram of grid slopes and histogram of grid distances to rivers. These 2 histograms will be used to compare the geo-similarity between sub-catchments and

Keywords: interception, hydrological processes, green infrastructure, rutter model
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the dimension of these 2 histograms are 255. The hydrographs of each sub-catchments were calculated using a distributed model. The rainfall events used in this study include 2 largest rainfall in the past 50 years of Sendai area: the 2019-10-11 rainfall (402mm) and the 1986-08-03 rainfall (401mm).

The geo-similarity between sub-catchments were compared using the Jensen–Shannon divergence (JSD) method. This method can estimate how similar catchments are with respect to their features distributions. JSD is based on the well-known Kullback–Leibler divergence (KLD; sometimes referred as relative entropy), defined as:

$$D_{KL}(X||Y) = \sum_{x \in X}^{p} (x_i) log_2 \frac{p(x_i)}{p(y_i)}$$

where p(xi) and p(yi) are the probabilities that X and Y are respectively in the states xi and yi. In brief, KLD quantifies the information loss when the probability density function of Y is used in place of X. From this, the JSD is developed by comparing each distribution to the “midpoint” distribution M, defined as

$$M = \frac{1}{N} \sum_{i-1}^{n} (X_i + Y_i)$$

Accordingly, the JSD represents the average divergence of N probability distribution from their midpoint distribution, A high JSD value indicates a high divergence between the distributions, with a maximum of 1. It is defined as

$$JSD = \frac{1}{N} \sum_{i=1}^{N} D_{KL}(X_i||M)$$

The hydrological similarity between sub-catchments were compared using the r2 index which is very widely used in hydrology field:

$$r^2 = \left(\frac{\sum_{i=1}^{n} (Q_{1,i} - \overline{Q_1})(Q_{2,i} - \overline{Q_2})}{\sqrt{\sum_{i=1}^{n} (Q_{1,i} - \overline{Q_1})^2 \sum_{i=1}^{n} (Q_{2,i} - \overline{Q_2})^2}} \right)^2$$

3. RESULT AND DISCUSSION

Figure 2(a) displays the similarity matrix of the histogram of distance to river for the 83 sub-catchments examined in this study. The fact that these distributions are relatively similar is also indicated by the JSD and the values of which are all rather small, indicating low divergence between the distributions.

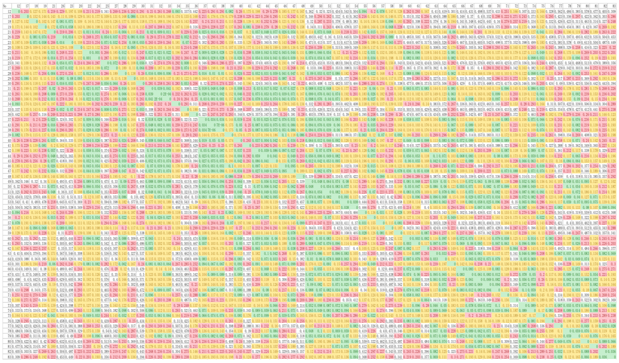

Fig. 2. JSD values for the 83 research catchments between the histogram of distance to rivers. Green: <0.1, yellow: 0.1~0.2, red:>0.2.

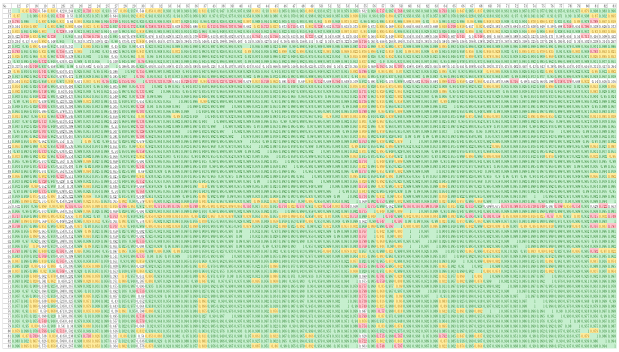

Fig. 3. R^2 values for the 83 research catchments between the hydrographs.

4. CONCLUSIONS

From the evaluation results, it is possible to estimate a similar water discharge prediction using the similarity of topography features. Although the accuracy is not so high, Results showing that the hydrological similarity is reflected using the geo-similarity. Even though the possibility of obtaining the relationships have been proved, it is expected that accuracy should be improved by future studies.

ACKNOWLEDGEMENT

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in Aid for Challenging Research (Exploratory), 2019-2021（19K21982, Daisuke Komori）. The author thanks the Water Resources Bureau for providing drainage network data and the permission for monitoring discharge at the outlet.

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