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Hydrology and Water Resources in Monsoon Asia —A Consideration of Necessity to Organize “Asian Association of Hydrology and Water Resources”—

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I. INTRODUCTION

“The basic concepts of investigating hydrological processes were developed in Europe and refined and further improved in North America. It is quite natural, therefore, that the methods usually applied to describe the continental branch of the hydrological cycle are fitted to the geographic and climatic conditions prevailing in those areas. Both Europe and North America – at least their greater parts – belong to the temperate zone, large areas having humid or semi-humid climates and undulating topography. Therefore the conventional hydrology in those continents is based on the determination of catchment-response to precipitation. —When the development of hydrological sciences became linked to a large international program, the limitations to the application of conventional methods in areas with different characteristics were immediately recognized—.”

This is referred from a paper entitled “Proposal to construct a coordinating matrix for comparative hydrology” written in 1984 by G. Kovac who served the President of IASH at that time. The above description expresses very well the background of the development of hydrological sciences and their limitations. The purpose of his paper was to provide a framework for comparative

hydrology by defining “specific regions” in which common hydrological conditions take place. By combining morphological and climatic conditions, he proposed a new systematic categorization of specific hydrological regions. In this categorization, morphological conditions are classified into three sub-divisions such as flat lands, sloping terrains and mountainous regions according to the gradient of the land slope. The categorization proposed by Kovac is systematic and overall, and might be useful for huge continental river basins. It is partly used as sub-topics for “hydrological problems of specific regions” in the IHP research projects. However, it is too detailed to be applied for relatively small-scale river basins like those in Asian region.

Usually we consider hydrological characteristics for a start in a river-basin scale in which a series of mountainous areas, sloping terrains and flat lands are included. The purpose of this paper is to propose more macroscopic hydrological regions that enable to express hydrological characteristics common in a river-basin scale especially for the Monsoon-Asian region.

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II. THREE MAJOR FACTORS GOVERNING HYDROLOGICAL FEATURES

Generally in the past study on the classification of hydrological regions including Kovac's one, the morphology of terrain and the climate are considered as decisive factors characterizing regional hydrology. We also adopt these two factors, geomorphological and climatic factors, in this paper. These factors represent natural conditions for hydrology. However the hydrological features in the river basin are different not only by natural conditions, but also considerably modified by human activities. Especially, more than 60% of the earth's population live in the humid climate region influenced by Asian monsoon, different from arid, semi-arid and semi-humid regions, and an appreciate number of human beings live even in mountainous areas in the region. Therefore, we have to take various effects of human activities into account as an important decisive factor modifying the hydrological features. Then, we introduce this decisive factor as "human intervention to the natural environment".

In summary, three major factors, namely geomorphological factor, climatic factor and human intervention to the natural environment, are considered here in this paper to discuss the similarity of hydrological phenomena in the Asian region. Hydrological features in the river basin should be considered in a dynamic interaction among these three factors, as shown in Fig. 1.

Fig. 1 Three Major Factors governing Hydrological Features in the River Basin

1. Geomorphological factor

The term "geomorphology" means the form and structure of terrain, or both topography and geology. The geomorphological factor, associated with land cover conditions, has predominant effects on every hydrological processes on the ground such as surface runoff and stream flow, infiltration and percolation, groundwater storage and runoff, sediment yield and transport, etc.. In addition, the factor is a decisive factor for human beings to determine the land use.

What can we adopt to express the geomorphological factor characterizing the Asian region?

From a global point of view, the continent masses consist of two basic subdivisions: one is an active belt of mountain making and another is an inactive region of old rocks (Strahler *et al.*, 1992). The mountain-making activity on the earth is caused by plate tectonic motion and the belts are called "tectonic zones". The inactive region is called "stable region" hereafter in this paper.

There are two principal tectonic zones: one is Alpine-Himalayan zone and another is circum-Pacific zone (Fig. 2). The Alpine-Himalayan zone runs from Alps and Mediterranean coast, through Middle and Near East, to Himalayas and then to Malay peninsula, Sumatra and Java islands. The circum-Pacific zone runs from New Zealand, through New Guinea, Philippines, Taiwan, Japan and Aleutian islands, and also along eastern fringe of Asian continent like Vietnam, southern and eastern China, Korea and northeastern Russia, then to west coasts of both north and south American continents. Land (topographical and geological) conditions in these tectonic zones are remarkably different from stable regions, and consequently characteristics of river basins from the hydrological point of view are distinctly distinguished between tectonic zones and stable regions.

As a conclusion of the above discussion, it can be said that two basic categories based on geological structure, namely tectonic zones and stable regions (inactive regions of old geology), are quite suitable to express primary characteristics of geo-

Fig. 2 World Distribution of Tectonic Zones (Strahler *et al.* 1992)

morphology on the earth. The tectonic zones cover large parts of Asia and have great influences on hydrological processes in almost of all river basins in Asia.

Hydrological characteristics in river basins along tectonic zones are described in Section 3.

2. Climatic factor

Most common approach to the classification of the climate from the hydrological point of view is a combination of two parameters, namely aridity and latitude. The aridity index (α) is defined as the ratio of potential evapotranspiration (ETP) to precipitation (P) given by

$$\alpha = \text{ETP}/P$$

Here, ETP and P both represent annual average values. If α less than unity, the region is classified as humid, whereas if it is greater than unity, the region is classified as arid. If α greater than 1 on annual basis but become less than 1 during some part of year, the region is classified as semi-arid, whereas the regions for opposite case where α is less than 1 for annual average but becomes greater than 1 during some part of year are termed as semi-humid.

Usually five zones are distinguished according to latitude: arctic, sub arctic, temperate, subtropical and tropical. Their borders can be defined basi-

cally by given values of latitude, although may be modified due to oceanic effects as well as orographic conditions.

The combination of two climatic parameters makes twenty possible categories, but twelve categories out of twenties exist actually on the earth as follows; humid arctic, humid sub arctic, humid temperate, humid tropic, semi-humid sub arctic, semi-humid temperate, semi-humid tropic, semi-arid temperate, semi-arid sub tropic, semi-arid tropic, arid temperate and arid sub tropic (Kovac, 1984).

Then, what climatic regions are East, Southeast and South Asian region classified into?

Let us take the Chao Phraya river basin in Thailand as an example. The basin is classified into semi-arid according to the conventional definition of aridity index, since the annual precipitation is about 1,200mm and the potential evapotranspiration about 2,000mm. However almost of all annual precipitation appears during the rainy season from May to October when it is quite humid and everywhere of flat lands are inundated with heavy rainfall. It is not fitted for our feeling that Thailand is defined as semi-arid. In a large part of monsoon Asia, there is plenty of rainfall during the rainy season. In such a case, we should consider not only the ratio of ETP to P, but also

Fig. 3 World Distribution of Annual Precipitation (Average of 1979-1999)

the absolute value of P . Tentatively, if the annual precipitation is greater than 1,000mm, then the region is defined as humid. Thus almost of all East and Southeast Asian regions are involved in humid climate (Fig. 3).

As for the latitudinal categorization, the summer in East Asian countries like Japan, Korea and part of China located in temperate zone has high temperature similar to Southeast and South Asia located in the tropical zone. Therefore, from a macroscopic point of view, we put temperate and tropic together in the same category, which is defined here as "warm" zone.

The combination of "warm" and "humid" both defined here makes a new climatic region named "warm-humid". The warm-humid climates cover a large part of Asian region.

3. Human intervention to the natural environment

Based on the above discussion, "warm-humid tectonic zone" is proposed as a new macroscopic hydrological region. We can observe many types of human activities particular to the warm-humid tectonic zones, such as paddy cultivation, slope ag-

riculture, location of urban areas in alluvial flood-plains, protection of alluvial plain from inundation, etc. The interrelationship between human activities and natural conditions in the zones are discussed in the following section and illustrated in Fig. 4.

III. HYDROLOGICAL FEATURES COMMON IN RIVER BASINS ALONG TECTONIC ZONES

Hydrological characteristics in tectonic zones, contrasted to those in stable regions, are enumerated together with the human intervention corresponding to the characteristics below:

- Most of all high mountains in the world are located in tectonic zones.
- The land is structurally unstable as a result of tectonic plate motion over the past 200,000,000 years, and the motion is still taking place.
- The tectonic zones are characterized by seismic and volcanic activities, and have similar geological components such as igneous rocks, volcanic products, Tertiary formations, fractured zones, etc.,

—Basin geology greatly affects the hydrological

Fig. 4 Hydrological Characteristics Common in Warm-Humid Tectonic Zones

regime, the river configuration and the feature of alluvial plains.

- The mountain slope cultivation is carried out on slopes of volcanoes, fractured zones, Tertiary formation and weathered granite areas.
- The steep slope and fragile geology bring about high sediment yield, slope failure, landslide and debris/mud flow in mountainous areas. Sabo engineering works (debris control, landslide and slope failure prevention works) are applied to prevent or mitigate damages caused by them.
- The scale of plains is relatively small in tectonic zones. Large plains in the world face mainly Atlantic and Arctic Coasts.
- Catchment areas of rivers in tectonic zones are generally smaller than those in stable regions, because of relatively short distance from the mountain to the seashore.
- The size of river basins in the zones is suitable for the integrated river basin management.
- For the same reason, the slope of riverbed is

relatively steep.

- Plains in tectonic zones are mainly alluvial plain, formed up by flooding of rivers, while those in the other regions are mainly structural plain, of which the surface is composed of residual soils.
- In general, the alluvial plain in tectonic zones is composed of three topographical units; alluvial fan, natural levee area and delta. On the other hand, most portions of the river course in stable regions are erosive valley, and the alluvial plain is usually limited in the delta area near the river mouth.
- The alluvial plain is the most important place for people's lives and industrial activities in tectonic zones, while the major human activities in stable regions are placed on relatively high lands with gentle and undulating topography.
- Since the alluvial plain is low-lying and wet land, it is used for paddy cultivation if the high temperature and sufficient water can be obtained. The paddy cultivation has special water management technologies different from other

field crop cultivation in stable regions.

- ・ It is the most densely populated area in tectonic zones; big cities, towns and villages are located in the low-lying alluvial plain, while they are located generally in undulating high lands in stable regions.
- ・ Alluvial plains, formed up by flooding, have a nature vulnerable to be flooded.
 - Therefore, flood control and flood disaster mitigation measures are much more important in tectonic zones than in stable regions.
- ・ The concept of flood plain management is remarkably different between tectonic zones and stable regions;
 - In case of flood plains along the erosive valley in stable regions, they apply mainly non-structural measures such as land use restriction without the construction of flood control facilities like embankment.

IV. DIFFERENCES IN RESEARCH SUBJECTS OF HYDROLOGY AND WATER RESOURCES BETWEEN TECTONIC ZONES AND STABLE REGIONS

Physical, chemical and biological principles governing the hydrological phenomena are general and common in the world. However, the phenomena themselves appear very differently, region by region, strongly affected by geographical conditions. Usually, researchers and practitioners in the field of hydrology and water resources deal with subjects surrounding them. It is difficult even for an excellent researcher to develop the study on hydrological phenomena which does not exist surrounding him. In this sense, hydrological studies tend to be site-specific. Therefore, scientific concepts and/or methods developed in a specific region are not necessarily applicable to other regions. Also, targets of research in a specific region may differ from those in another region. Some examples representing those differences between warm-humid tectonic zones and stable regions are listed up below:

- ・ The original version of SHE (Système Hydrologique Européenne) Model, one of the most so-

phisticated distributed hydrological models, does not have a component of lateral sub-surface flow, since it was developed in gently undulating terrains. Therefore it is very difficult to simulate the stream runoff in river basins with steep gradient and thick surface soil of mountain slope (Jha *et al.*, 1995).

- ・ SiB2 (Simple Biosphere Model 2), one of the latest Land Surface Model, does not have the scheme for paddy fields. The scheme was developed in the research related to the GEWEX Asian Monsoon Experiment (GAME), and using it, the results of simulation were much improved (Kim *et al.*, 2001).
- ・ The source of sediment yield in stable regions is mainly soil erosion, and the soil erosion process is formulated as Universal Soil Loss Equation (Wischmeyer and Smith, 1965), Revised Soil Loss Equation (Wertz *et al.*, 1987), etc.. We have other major sources of sediment yield particular to tectonic zones, such as landslide, mountain-slope collapse, debris/mud flow and volcanic eruption. Although the estimation and prediction of sediment yields from these sources are very difficult due to their discontinuous nature, systematical studies on them should be organized in our region.
- ・ In Europe, “karst hydrology” becomes a specific field of hydrology, since limestone areas which have special hydrological conditions are widely distributed. Volcanic areas located in tectonic zones also have special conditions, but we do not establish yet a specific research field of “volcanic hydrology”.
- ・ The awareness of flood plains seems to be considerably different between warm-humid tectonic zones and stable regions. Generally in stable regions, most of river reaches are erosive and in those reaches the bottom of valley is flood plain, which is relatively only limited areas. Most of population lives on undulating terrains above the valley. On the other hand, in the tectonic zones we have large alluvial flood plains along the middle and down reaches of river, where a lot of people live and human activities

are most active. Therefore the idea of flood-plain management is basically different between two regions.

- The awareness of river basin is somewhat different between arid/semi-arid and humid regions. In the arid/semi-arid region where the water resources depend mainly on the ground water, the awareness of river basin is very weak. On the other hand, in the humid region where the water resources depend mainly on the river water and the flood inundation often takes place in the alluvial plain, we have much concern to the river basin.

These are only limited examples relating to the author's research subjects. We can find out a lot of other specific research topics particular to tectonic zones in monsoon Asia. Studies on characteristics of monsoon rainfall and its prediction are also very important research subjects in our region.

V. SUMMARY

In this paper, the main focus is placed on how to recognize the "too much water" problems in monsoon Asia, which are not reasonably addressed in the world-wide international societies led by western people. For this purpose, the author introduced a new macroscopic hydrological region defined as "warm-humid tectonic zones", indicating that geomorphological conditions particular to tectonic zones should be considered together with abundant precipitation due to Asian monsoon, and discussed water resources issues and research subjects particular to the zones. Using the macroscopic classification of tectonic zone and stable region, differences in "too much water" problem between two regions may be more clearly recognized.

On the other hand, there are also arid, semi-arid and semi-humid areas in monsoon Asia. Although the "too little water" problems were not discussed in this paper for the above-mentioned reason, we have many research and practical subjects to be solved for the water scarcity in a geographical region of monsoon Asia.

In order to encourage and promote cooperative

research activities in monsoon Asia, Japan society of Hydrology and Water Resources is just proposing to establish a standing research community, tentatively named "Asian Association of Hydrology and Water Resources".

The 3rd World Water Forum will be held in Kyoto, Japan in March 2003. Hopefully, we would like to establish such an Association under the close linkage and collaboration with Asian-Pacific countries before the 3rd Forum.

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