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JSPS-DGHE Joint Research Project

International Workshop on Integrated Watershed Management for Sustainable Water Use in a Humid Tropical Region

Tsukuba, Japan
31 October, 2007

Proceedings

Edited by T. TANAKA

Bulletin of the Terrestrial Environment Research Center
University of Tsukuba, No.8 Supplement, no. 2
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Preface

Water resources in the Asia region are very severe and scarce that should be supplying by only 36% of world's water resources amount for a half of population in the world. In addition, a very rapid population increase is apparent in recent years and the problem is getting very serious. This rapid population increase causes not only increase of water demand but also affects largely the land use change, which causes land degradation, soil erosion, change in hydrologic regimes and environmental qualities. In the past century, the land use change in the Asia region occurred from the forest to agricultural uses, but in the last few decades the land use conversion has been mostly from the agricultural to non-agricultural uses. For example, in Indonesia, the critical watershed reached up to 60 watersheds with areal extent of 43 million hectares in 1998 and has increased to 59 million hectares in 2005, and the extent of these critical watersheds influences strongly on the regional hydrological condition and the water resources status.

To overcome those water crises, it is necessary to clarify the causes and effects of watershed hydrology aspects on water resources conservation through the collaborative research among Asian countries by developing a methodology and analytical methods for the desired watershed management. It is also necessary to enhance the technology transfer, the capacity building and the water governance to maintain and continue the established watershed management for sustainable water resources development, water uses and its conservation in a future.

The JSPS-DGHE (Directorate General of Higher Education, Indonesia) Joint Research Project on "Watershed Management for Sustainable Water Resources Development in a Humid Tropical Region" has been launched in 2007 for three years continue project. The purpose of the project is to clarify what the desired watershed management should be for sustainable water resources development and water uses with an emphasis on the land use management for water resources conservation and to construct a new model of "Integrated Watershed Management" which will lead the decision making together with the capacity building and the water governance.

The Proceedings contain 9 papers of the project members presented at the International Workshop on Integrated Watershed Management for Sustainable Water Use in a Humid Tropical Region held at University of Tsukuba, Japan on 31 October, 2007. This workshop was organized by Prof. T. Tanaka, PI of the Project, Director of Terrestrial Environment Research Center (TERC), University of Tsukuba and sponsored by JSPS and TERC.

We hope that this initiative of the project and its deliberations will bring benefit to many of us and the concept of an integrated watershed management by supporting with the framework of capacity building, water governance and decision making process will be widely spread in Asia regions in near future.

29 February, 2008
Organizer
Prof. Dr. Tadashi TANAKA
PI of the JSPS-DGHE Joint Research Project
Director of Terrestrial Environment Research Center
University of Tsukuba

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Proceedings of International Workshop on Integrated Watershed Management for Sustainable Water Use in a Humid Tropical Region, JSPS-DGHE Joint Research Project, Tsukuba, October 2007. Bull. TERC, Univ. Tsukuba, No.8 Supplement, no. 2, 2008

Resource management issues of environmental services in a Changing upper watershed: the case of Cicatih-Cimandiri basin, West Java

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Abstract Development of the Cicatih-Cimandiri basin in the past decades has been characterized by burgeoning of bottled drinking water companies that utilies springs and groundwater resources, along with the traditional agricultural uses and local domestic water supplies. The present paper tried to discuss the resource management issues and to describe the resources of the upper forested watershed and their environmental services. The biophysical conditions will be explored to find ways to understand the watershed functions and to find measures of environmental services. There is a strong indication that local community tends to utilize the Cicatih water resources efficiently and very willing to pay for environmental services such as to pay compensation for conversation cost to ensure the sustainability of upper watershed resources. The same thing needs to be done by the drinking water companies in the area that apparently would require more efforts to come to common understanding on sustainable resource management through accepted policy and principles.

Keywords upper watershed, resource management, environmental services

INTRODUCTION

Watershed as biophysical land system has a set of functions such as: production, ecological, habitat, esthetical, and social functions. The production function of a watershed not only in terms of wood of forest products or agricultural products, but also other material products, including water as flowing resources that plays essential role in maintaining life on earth and provide environmental services. Environmental services of watershed resources quite often are not realized by most people and these were more because of limited understanding of the resources and water resources were taken for granted as common goods. In the case of Cicatih-Cimandiri basin, surface water as streamflow and springs have been used by local people for all their water needs, such as for domestic uses, irrigation and other agricultural water uses, fisheries and recreation. Recent development in the area was characteized by the emergence of bottled drinking water companies that mainly make use of springs and groundwater resources. Spring waters play very important roles for the livelihood of the local people in the area, and this recent development poses potential conflicts of interest between parties, all the stakeholders consisting of local community, industries, government and non-governmental organizations, and the State Forest Company as the main player in managing forested upper watershed. Therefore to avoid these conflicts they become important issues to find proper management of the watershed resources based on accepted management principles.

The present paper tried to discuss the resource management issues and to describe the resources of the upper forested watershed and their environmental services. The biophysical conditions will be explored to find ways to understand the watershed functions and to find measures of environmental services.

STUDY OBJECTIVES

The study objective is to provide description of the study area and its watershed resources, and to assess the resource management issues that determined environmental services of changing forested watershed.

THE STUDY AREA

The study area is located about 40 km south of the City of Bogor which is situated between the south slope of Mount Salak and Mount Pangrango. Figure 1 shows the schematic map of the study area relative to City of Bogor.

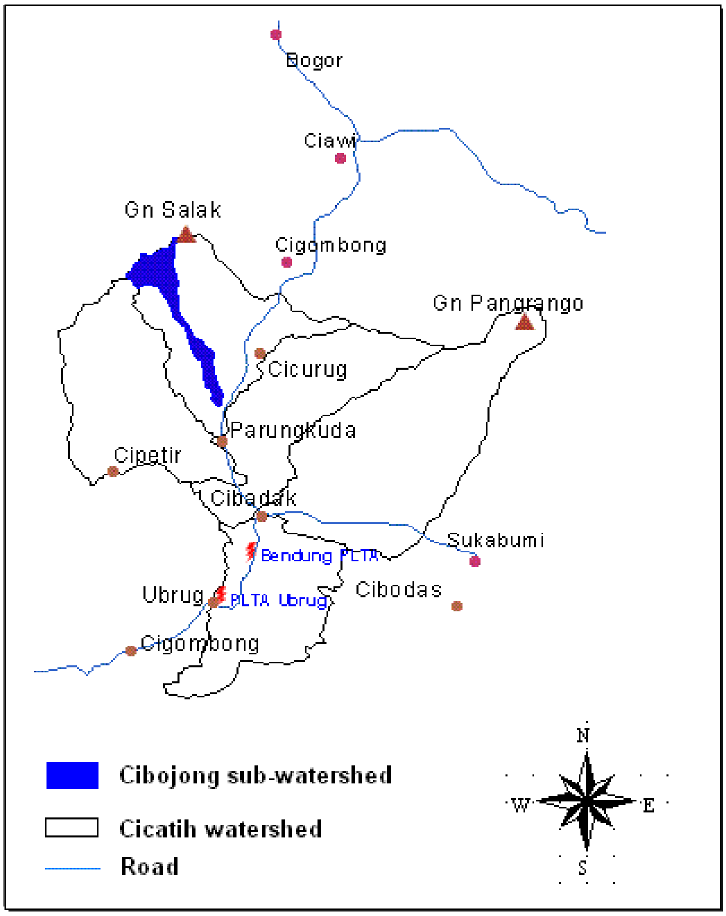

Fig. 1 Location map of the study area.

BASIN DESCRIPTIONS

This study area is the Cicatih-Cimandiri basin with an area of 530 sq.km which is the upper watershed of a major river basin in West Java and discharging its flow to the south coast direct to the Indian Ocean. The high points of Cicatih basin are marked by Mount Pangrango to the north east at 3018 m asl and Mount Salak on the north west at

2217 m asl and the downstream parts are characterized by densely populated valley with the lower point at 200 m asl with a hydropower station of PLTA Ubrug that was built in 1930s. Very steep lands of over 45% slopes represent only 7% of the basin area, with 60% areas have less than 15% slopes. Figure 2 shows the topographic picture of the Cicatih basin with locations of available rainfall stations. The low flows at Ubrug was expected at 12 m^3/s, but biophysical changes in the last few decades had lower it to about 5.0 m^3/s and average high flows at 230 m^3/s. Annual average rainfall was 2970 mm with marked seasonal differences.

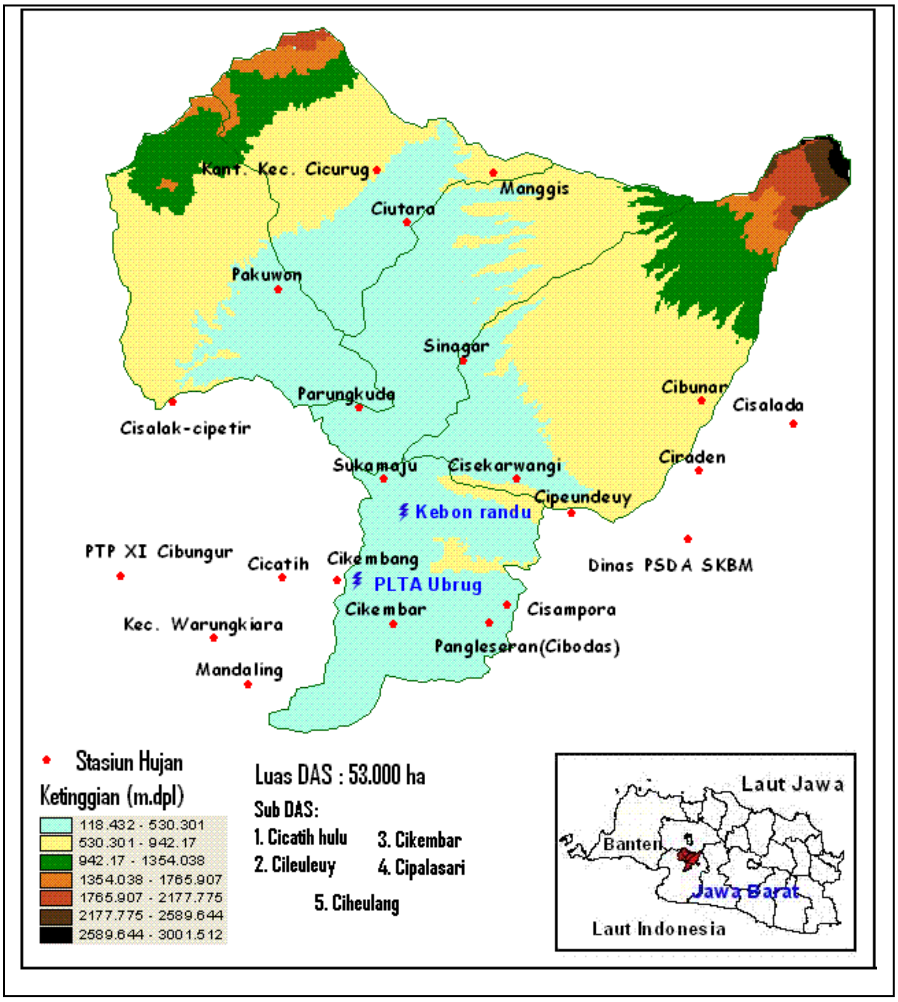

Fig. 2 Cicatih-Cimandiri basin topographic map with locations of rainfall stations.

The physiography of Cicatih basin with its geologic characteristics is endowed with abundance of water springs along the slopes and valley to satisfy the needs of local community, agriculture, and recent commercial development of drinking water companies of different economic scales. Two largest water springs are of Cipanas spring discharge outflow at 2.500 liters/s partly being used by local public water company and the other Cibuntu discharged at 695 liters/s that mostly is being used by local people for various needs, while many other smaller ones are occupied privately, such as by: Aqua Danone, Tang Mas, Aquina, Tirta Sejuk, Ades Alpindo, Bakso Mas, Tirta Food, Aires, Tirta Babakan Pari, Tri Banyan Tirta, and Agrawira. Accurate descriptions of the basin biophysical features is necessary to understand the interrelationships between the different factors and water resource components of the basin and the beneficiaries of environmental services, among others to know the people perceptions on resource management issues to ensure their sustainability.

Present land uses are dominated by food crops and mixed garden, including tea and coconuts (45%), follows by natural forest (21%) at the upper parts, and the rests are paddy fields, scrubs, grasslands and settlements. The Cicatih basin consists of five subbasins: (i) Upper Cicatih (18.76%); (ii) Cipalasari (17.57%); (iii) Ciheulang (30.03%); (iv) Cileuleuy (17.43%); and (v) Cikembar (16.21%). Table 1 presents the breakdown of the different landuses according to the subbasins, indicating the nature of the basin and complexity of its landuses. Important recent development in the area is the burgeoning of bottled drinking water companies that reached more than 30 in number, including few largest ones, such as Aqua Danone and Ades. All these represent the biophysical background of the basin that is facing a declining capacity of the water resources in the middle of increasing conflicting interests. This paper would try to address the watershed resources management issues considering the environmental services in a changing land use settings in densely populated area.

Population: administratively, the Cicatih basin is represented by Cidahu subdistrict that accomodate around 54 thousand people distributed into eight villages with average population density of 2100 orang/km^2 (see Tabel 2). Low education background up to primary schooling represent 80% of the population and 88% are farmers that occupied 67% of basin area, and 65% of these farmers are landless.

Sources of domestic water are shallow groundwater for 4301 households and 444 households use local public water company. Land use change was recorded from PODES data (2003) to occur at Pondok Kaso Tengah village with 11% paddy field conversion and 2% for settlements. No change occured for other villages.

Table 1 Percentages of land use types according to the sub-basins.

Land use type	*Upper Cicatih*	*Cipalasari*	*Cileuleuy*	*Ciheulang*	*Cikembar*
Forest	15.34	13.10	12.70	25.69	0.68
Scrubs	7.08	7.52	9.60	12.89	2.26
Food crops	15.36	11.27	38.08	8.04	24.39
Grass	0.11	0.14	0.34	0.19	0.50
Mixed garden	18.33	44.89	22.19	12.47	45.85
Paddy fields	28.52	11.72	7.03	27.88	13.04
Settlements	15.22	11.35	10.06	12.84	13.21
Water bodies	0.04				0.07

Table 2 Characterisitcs of population by villages of Cidahu Subdistrict.

No	Village	Population			Area (ha)	Pop. Density	Sex Ratio
		Male	Female	Total			
1	Pondok Kaso Tonggoh	3.198	2.947	6.145	100	61	109
2	Babakan Pari	3.053	2.664	5.717	217	26	115
3	Pondok Kaso Tengah	2.679	2.646	5.325	259	21	101
4	Cidahu	4.831	4.232	9.063	1.224	7	114
5	Tangkil	3.967	3.414	7.381	319	23	116
6	Jayabakti	5.189	4.876	10.06	320	31	106
7	Girijaya	3.207	3.076	6.283	357	18	104
8	Pasirdoton	2.385	2.018	4.403	121	36	118
	Total	28.509	25.873	54.38	2.694.2	21	110

Source: Monthly population report Cidahu Subdistrict, 2005.

WATERSHED RESOURCES

Much of the watershed resources for Cicatih basin still needs further investigation, through field study of land use changes; investigate streamflow data and other biophysical aspects such as rainfall data availability that cover the watershed. The hydrologic budget of the basin would be the basic analysis to reveal the available water resources. Table 3 below presents a simple annual water balance indicating the high runoff index. Since 2002 annual streamflow data was below 2000 mm.

Table 3 Water balance of Cicatih watershed in mm/year.

Year	Rainfall (RF)	Discharge (Q)	RF-Q	RI
1999	2412[1]	2075[2]	337	0.86
2000	2498	2062	436	0.83
2001	3223	3008	215	0.93
2002	2035	1816	218	0.89
2003	2299	1600	699	0.70
2004	1583[3]	1778	-195	1.12
2005	3121	1807	1314	0.58

Missing data: [1]Dec; [2]Apr and Nov; [3]Oct-Nov.

RESOURCE MANAGEMENT ISSUES

Water resources in Indonesia are bound to the recent Water Law issued as state law No.7 year 2004. The law stated that water resources management includes planning, implementation, monitoring and evaluation of water related activities that consist of conservation, utilization and control of damaging forces within any water resources region. It should managed integratively between surface water and groundwater, considering sustainability pinciple, balanced among social, environmental, and economic aspects. Resource management principles adopted are public welfares, fairness, self relience, transparant and accountable, as a general rule the resource management should be elaborated in the form of management plan of the water resources. However in the field such as the case of Cicatih basin, all of this legal guidance is not recognized in existence. The limited resources with many growing stakeholders stance potential conflicts without proper management, and to facilitate this it is instrumental the role of academicians with sufficient knowledge of limitations of available resources and perceptions of the different stakeholders, also with increasing awareness of the importance of environmental services of natural resources such as forested upper watershed.

The goals of resource management should be understood by all stakeholders through active participation and expressed as common efforts acknowledging the roles and responsibility of each party. The case of Cicatih basin, the upper most areas that are covered by forests are managed by state owned forest corporation called PT Perhutani. A buffer zone to the private owned areas should be extablished to avoid further encroachment to the forest, and the mosaics on the lower section of the basin should be managed following good management practices and these is obvious to the public due to their intensive uses. Though some field hydrologic studies had been done in the areas, better knowledge of the water resources is still necessary in role sharing among stakeholders and on water allocations. What are the roles and contribution of each stakeholder for sustainability of environmental services. It was recognized that the water resources have been experiencing heavy pressures from the many water users and the changing land uses, however there is no measure yet as to judge the sustainability of these natural resources in the near future. If exploitation of groundwater by new drinking water industries should be avoided or present level of agricultural practices should be reduced, and how much reforestation would be necessary and where? If reforestation is an effective and good decision? There are many issues and questions need to be answered yet and time is pressing to ensure not only resources sustainability but also survival and people welfare in the future, and it is considered necessary to generate basic information that would be needed to obtain good description of the biophysical condition of the basin, its socio-economic and community institutional aspects, and public perceptions of the resource management issues. Public access to information such as disbursement of water resources tax should be opened in the new era of regional otonomy policy. Serious issue concerning the environmental services is due to intensive water uses with dense population, however with low education level and high unemployment.

In general, most of population faced water shortage problem, even they had difficulties to take bath sufficiently. People used to take two or three times bathing a day were being asked for reducing the frequency into only once or so a day. This indeed the severest water shortage they ever face so far. Compared to other long drought of 1997, the shortage is considered worst which even makes upstream river completely drained.

Water shortage was not only posed population risk to health issue, but also faced even bigger problem in term of lost income opportunity of agricultural production, that accrued for more than 75 percent of people source of income. The problem population faced, in turn waking up community awareness on the roots of the problem. Communities pointed out several main causes of the water shortage recently, such as illegal logging, land conversion, lack of income sources, with strong perception of local wisdom stated as “live close to forest commit logging, close to river collected stone, and close to the sea go fishing”.

CONCLUSIONS

Resource management of environmental services has become an important issue in the study area due to conflicting interests of traditional and non-traditional water users considering the seasonal patterns of surface water availability, especially on springs and groundwater resources.

There is a strong indication that local community tends to utilize the Cicatih water resources efficiently and very willing to pay for environmental services such as to pay compensation for conversation cost to ensure the sustainability of upper watershed resources, but existing policy do not work in the same way for the water industries. Further indepth study is necessary on resources management issues for sustainable environmental services of forested upper watershed.

ACKNOWLEDGEMENT

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Transboundary watershed management: A case study of upstream-downstream relationships in Ciliwung watershed

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INTRODUCTION

Ciliwung watershed is an interesting watershed in term of size, position, and the governments involved in its management. The size of Ciliwung watershed is not so big, it covers the area of about 387 km^2, with the main river length of about 117 km. The river flows into the middle part of Jakarta, the capitol of the Republic of Indonesia, and involve 1 district and 5 municipalities (Bogor District, Bogor, Depok, South, Center), and North Jakarta municipalities of two provinces (West Java and Jakarta Goverments). Bogor district area mostly covers the upper part of watershed, and small part of it together with Depok Municipality area covers the middle part, and the municipals of Jakarta cover the downstream of watershed.

The rivers flow to Jakarta area actually is not only Ciliwung river, but there are some rivers, but the influence of Ciliwung river and its man made canal (west canal) into the Jakarta region is the biggest among the rivers flow to Jakarta (Figure 1). Therefore, the occurrence of flood in Jakarta is always related to Ciliwung watershed management, especially in the upper part.

Since the implementation of decentralized government system, where the smallest level of autonomous government is district level, then the management of watershed that covers more than one district become more complicated.

This paper presents the figure the Ciliwung watershed and its management during decentralized government system. Transboundary in this context means inter-district governmental management.

CILIWUNG WATERSHED AND ITS MANAGEMENT

The upper watershed that is upper area of Katulampa Dam/Gauging station covers the area of about 146 km^2. This area is mountainous area. Located at 300 – 3.000 m a.s.l. The slopes steepness of 2-15% covers the area of 70.5 km^2, 15-45% (52.9 km^2), and the rest is > 45%. The average annual rainfall of the period of 1989-2001 was 3,636 mm. There are many springs found in this upper watershed. The maximum discharge at Katulampa tend to increase, while the minimum discharge tend to decrease by year (Figure 2).

Based on Regional Land Use Planning of West Java Province 2010, this upper watershed is designed for conservation, agro industrial and agro tourism development through community empowerment.

The objective of this area development is to maintain the conservation function for sustainable water supply and flood control of downstream. To achieve this objective, the President decree (Keppres) No. 114/1999 was issued and state that until the year 2014 the 84% of this area must be functioned as the recharge area, and only 16% for business area (city development).

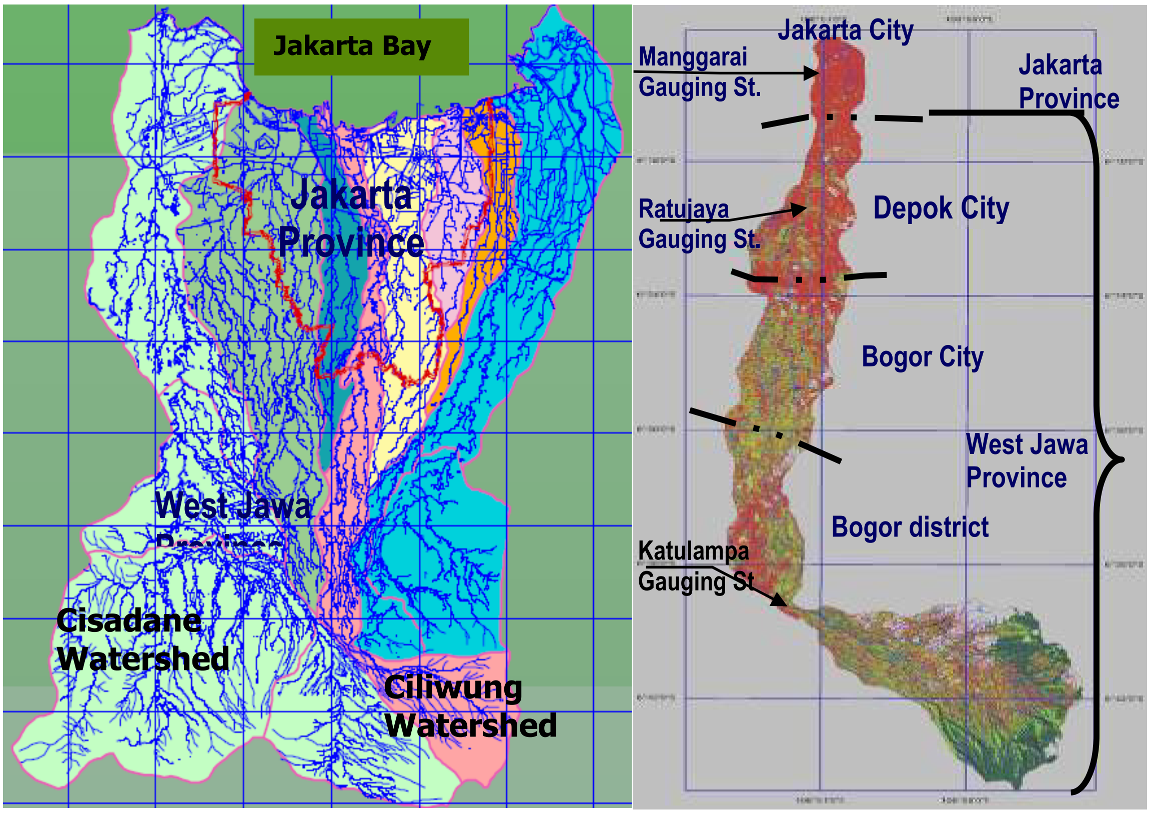
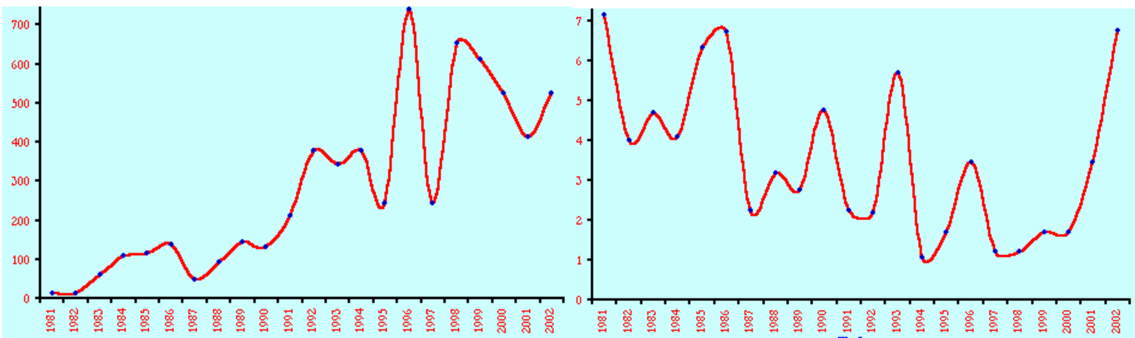


Fig. 1 The position of Ciliwung watershed among District/Municipality regions.



(A) (B)

Fig. 2 Maximum (A) and minimum (B) discharge fluctuation (1981-2002).

The middle part of the watershed that is the area between Katulampa and Ratujaya Gauging Station at Depok City covers the area of about 94 km^2. This area is located at 100-300 m a.s.l. and dominated by the slope steepness of < 15%. The average annual rainfall is 3,910 mm.

The downstream that is the area from Ratujaya to Manggarai gauging station covers the area of about 82 km^2. This area is dominated by flat area of < 2% slope steepness, and located at < 100 m a.s.l. The average annual rainfall is 2,126 mm.

The economic development of Jakarta, Depok, Bogor and other cities around Jakarta causes rapid change of land use from the green-vegetative areas to developed-buildings areas in Ciliwung watershed (Table 1 and Figure 3).

Table 1 Land use changes in Ciliwung watershed, 1970-2000.

Land Uses	1970		1980		1990		2000	
	Ha	%	Ha	%	Ha	%	Ha	%
Green and pen Areas	**25.687,99**	**66,35**	**22.474,57**	**58,05**	**18.289,38**	**47,24**	**15.079,84**	**38,95**
Agriculture and other green covers	15.312,13	39,55	13.817,70	35,69	13.066,61	33,75	10.478,55	27,07
Wet land and water body	10.375,86	26,80	8.656,87	22,36	5.222,77	13,49	4.601,29	11,88
Developed area	**13.027,90**	**33,65**	**16.241,31**	**41,95**	**20.426,50**	**52,76**	**23.636,04**	**61,05**
Housing	12.060,00	31,15	12.385,21	31,99	13.984,18	36,12	14.410,05	37,22
Indystry	193,58	0,50	1.711,24	4,42	2.470,07	6,38	3.883,20	10,03
Business area	774,32	2,00	2.144,86	5,54	3.972,25	10,26	5.342,79	13,80
Total	**38.715,89**	**100,00**	**38.715,89**	**100,00**	**38.715,89**	**100,00**	**38.715,89**	**100,00**

Source: Melati F.F., Hendrawan, D. and Sitawati, A.

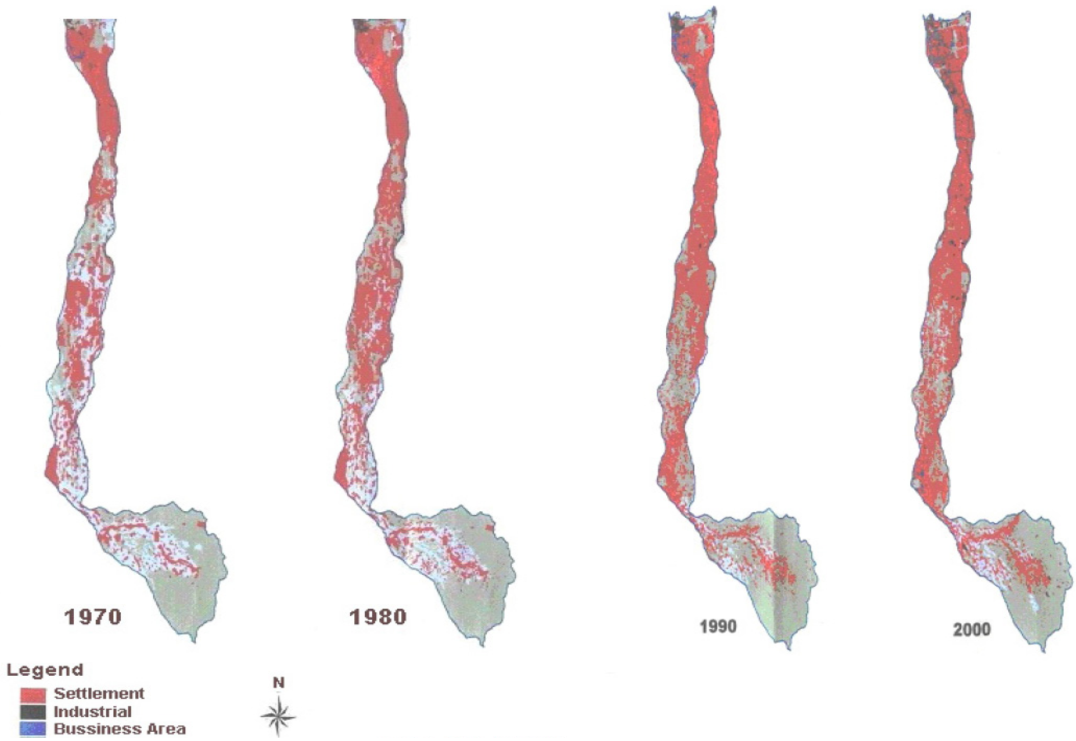


Fig. 3 Distribution of land use change in Ciliwung watershed, 1970-2000 (Melati F.F., Hendrawan, D. and Sitawati, A.).

Decreasing function of Ciliwung watershed indicated by land use changes from open green space to develop space with worse drainage system, frequent occurrence of flood and increasing of flood influenced area is the indicator of unsuccessful of watershed management which is also related to watershed governance. The (national) government and provincial government policies of land use of upper watershed are not strong enough to drive better land management activities in the upper watershed of Ciliwung.

CONCLUDING REMARKS

The weakness of coordination institution in watershed management is a problem that needed to be solved. The Provincial Development Planning Board (BAPPEDA) is hoped to be a coordination institution between or among districts/municipalities in regional development planning based on watershed development principles, but in fact the provincial-regional planning and watershed development planning are still two different planning, and also mostly the district-regional planning are less as an integrated provincial planning.

The weakness of coordination institution cause the districts/municipalities fail to formulate the cost-benefit sharing as an incentive system for environmental based development. As we know the environmental (economic long term) based development need more finance than the short term economic development. Consequently, the districts-regional development tends to be focused on short term economic development. The development of upper Ciliwung watershed is still far from the agro business and tourism development. The housing and settlement development is still dominant.

Driving factor for environmental development in upper watershed management as the water recharge for water supply to downstream should be created as an incentive system and initiated by related districts/municipalities or provincial province. In this case, Bogor, Depok districts/municipalities, West Java and Jakarta Provinces. The one success examples of this collaboration is collaboration of Kuningan District and Cirebon Municipality in upper watershed development, where Cirebon Municipalities Government agree to pay a certain amount of money to Kuningan District Government for upper watershed development to supply water to Cirebon Municiplas.

Multi stakeholders processes to build the inter governments commitment among Bogor district, Bogor, Depok and Jakarta Municipalities have been done several times through Watershed Management Forum, but those are still ineffective. Watershed Management Forum is loos coordination institution. To increase the effectiveness of the communication process, the mandatory coordination institution should be developed.

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Methodology of integrated watershed management for sustainable water resources use

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Abstract Water resources in the Asia region are very severe and scarce, and a very rapid population increase is apparent in recent years. This rapid population increase causes not only increase of water demand but also affect the land use change, resulting land degradation, soil erosion and change in hydrologic regimes. To overcome those water crises, it is necessary to develop a methodology and analytical methods for the desired watershed management. In the paper, the author proposed an integrated watershed management as one of the desired watershed managements for the next generation and showed a framework and a research flow of the management emphasizing the capacity building and the water governance as well as scientific researches on water resources issues.

Key words integrated watershed management, capacity building, water governance, decision making, OJT program, Sassari declaration

INTRODUCTION

Water resources in the Asia region are very severe and scarce, and a very rapid population increase is apparent in recent years. This rapid population increase causes not only increase of water demand but also affect largely the land use change, that is land degradation, soil erosion and change in hydrologic regimes. In the past century, the land use change in Asia regions occurred from the forest to agricultural uses, but in the last few decades the land use conversion has been mostly from the agricultural to non-agricultural uses. For example, in Indonesia, the critical watersheds reached up to 60 watersheds with areal extent of 43 million hectares in 1998 and have increased to 59 million hectares in 2005, and the extent of these critical watersheds influence strongly on the regional hydrological condition and the water resources status.

To overcome those water crises, it is necessary to develop a methodology and analytical methods for the desired watershed management. It is also necessary to enhance the technology transfer, the capacity building and the water governance to maintain and continue the established watershed management for sustainable water resources development, water use and its conservation in a future.

RESEARCH FRAMEWORK AND RESEARCH FLOW

The JSPS-DGHE (Directorate General of Higher Education, Indonesia) Joint Research Project on "Watershed Management for Sustainable Water Resources Development in a Humid Tropical Region" has been launched in 2007 for three years continue project. The framework and the research flow of the project are shown in Figs. 1 and 2, respectively. The specific objectives of the project are as follows:

1) Develop a new methodology and new technologies for water resources

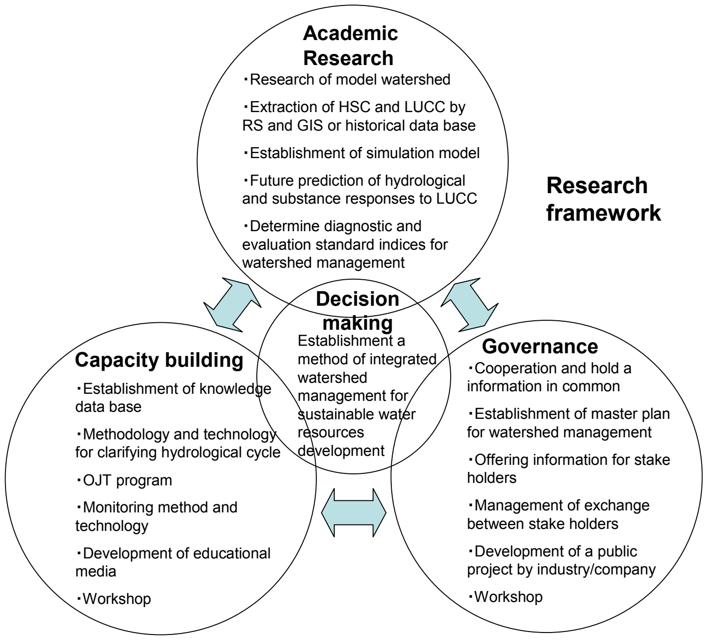

Fig. 1 Research framework of integrated watershed management for sustainable water resources development.

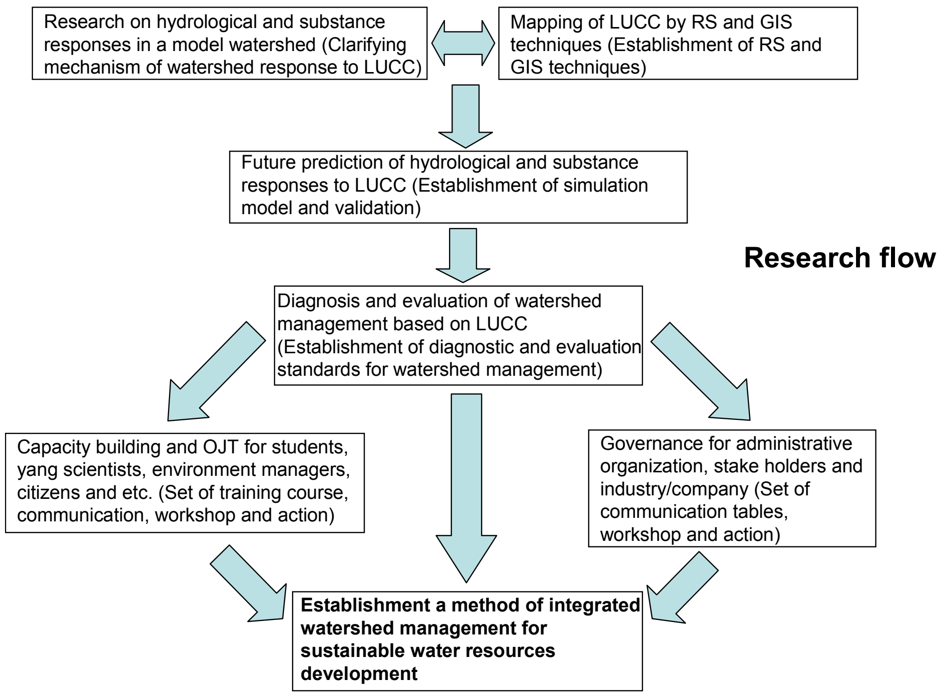

Fig. 2 Research flow of integrated watershed management for sustainable water resources development.

development, uses and conservation in a sustainable way as an integrated watershed management (Science Technology Aspect).

2) Understand the role of land use management and its impact on water resources conservation, livelihood, ecosystems and water resources services in selected different land use watersheds (Scientific Research and Ecohydrological and Socio-economic Aspects).

3) Enhance the technology transfer and the capacity building of individuals, communities and government organizations in managing land use for conserving water resources to promote sustainable water resources development and uses (Capacity Building Aspect).

4) Identify and promote appropriate institutions/organizations and develop support mechanisms in each of selected watershed to enhance the desired watershed management for sustainable water resources development, uses and conservation (Water Governance Aspect).

As mentioned above, the research framework constitutes with three parts of academic research, capacity building and water governance. In the academic research, it is important to extract the historical records of land use/cover change (LUCC) and hydrological structures/or resumes (HS) of a watershed using RS and GIS techniques or historical data base as well as inter-watershed differences of the subject, and to make clarify the inter-relationships and mechanism between the LUCC and HS. It is also important to determine the diagnostic and evaluation standard indices of watershed management for sustainable water use. Figure 3 shows the method of field investigation of hydrological cycle proposed by Kayane (1992) in Bali project. Almost 15 years has passed after the Bali project, it still valid as the method of field investigation of hydrological cycle because this figure includes already recent new technologies to clarifying hydrological cycle. Only the different point from this figure at the present time may be the resolution of equipments and the volume of available data sets.

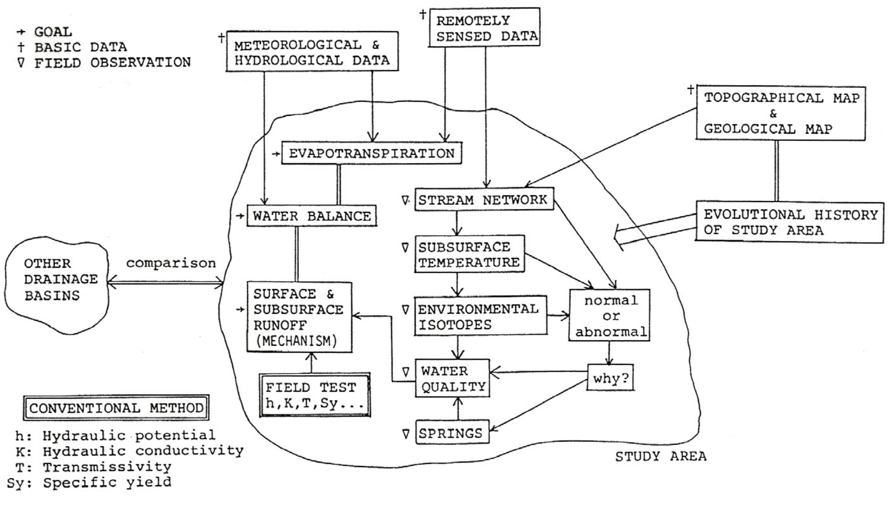

Fig. 3 Method of field investigation of hydrological cycle (Kayane, 1992).

For the capacity building, it is effective to make an On-the-Job Training (OJT) Program for students, technicians, yang scientist, environment managers, citizens and etc. As an example, On-the-Job Training Program for Water Resources Problem in China has been carried out by us with 20 trainers of graduate students and technicians (TERC, 2008). The purpose of the program is to build up knowledge, skill, incentive and general business capacity of young talent, and the program also includes the planning and training of field survey, the review of social and scientific backgrounds for water resources problem in China. Although, this is one of models of OJT, if the preparation of the program is enough well, it can work very effectively as one of methods of capacity building. Another important point regarding the capacity building is to become aware of the importance of continuous monitor the subject matters and to make the data base of its monitoring results. For this purpose, it is necessary to carried out a training course of monitoring methods and techniques for students, technicians and etc.

The most problem and thus difficult part of the framework shown in Fig. 1 may be the governance. This part includes relationships among local stakeholders, local leaders, government institutions companies and etc. The important point of this part is how to set communication tables/ places and who takes the leadership. Subagyono (2005) has pointed out the practice of governance as follows:

・Undertake community and local stakeholder workshops to review experiences and with focused on the particular roles and responsibilities of marginalized groups, communities, local leaders and government institutions in land use system management to enhance the available water resources.

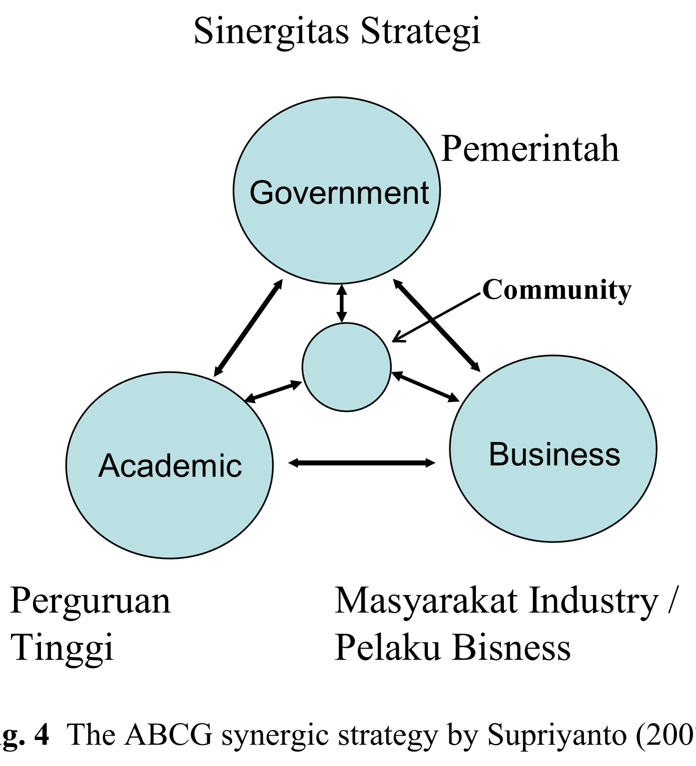

Fig. 4 The ABCG synergic strategy by Supriyanto (2007).

・Investigate options that would facilitate enhancing social processes, information flows, institutional incentives and other factors necessary for creating effective and inclusive institutional frameworks for assuring available water resource within each of target watersheds.

・Undertake workshops with members of rural extension and development services and regulatory institutions to improve institutional structures and policies that effect an enhancement in land use management for sustainable water resources.

・Conduct round table dialogue discussions with key decision makers to present results from research and other activities of the needs of communities in the target watersheds and implications associated with policy changes and implementations.

To success the governance, to get the results from academic researches of the subject is the first. In our case, the date and the results/information on hydrological response of a watershed against the dynamic of LUCC would be the necessary ones.

Regarding the forest conservation problems, similar strategy, called the ABCG Synergic Strategy, has been proposed by Supriyanto (2007) as shown in Fig.4. This concept also indicates the importance of mutual communications among stakeholders of ABCG for solving the environment problems such as forest and water conservations.

CONCLUDING REMARKS

In 2003, FAO organized a regional conference on the “Next Generation Watershed Management” at Sassari Province, Italy. Within the context of the Millennium Development Goals (MDGs) and with the intent of preparing for the next generation of watershed management, the purposes of this conference were to 1) provide an adequate opportunity/platform to all concerned parties to share information and contribute a better understanding of the current situation to watershed management, and 2) provide advocacy and support for the implementation of effective watershed management at different levels. The conference has adopted a declaration “Integrated Watershed Management: Water Resources for the Future” as the Sassari Declaration (FAO, 2003).

The Sassari Declaration has emphasized some of the key elements for the next generation of watershed management programs as: a multi-sectoral approach; a combination of bottom-up and top-down planning, monitoring and evaluation; clear procedures for environmental impact assessment of interventions including dams and reservoirs; networking among key stakeholders; consideration of both socio-economic and cultural aspects and natural processes; gender balance in decision making; embracing new approaches for sharing knowledge and learning; sustainable finance; competition mechanisms; capacity building at all levels; reforming governance; linking surface, groundwater and coastal water sources; shift from looking at supply to demand water; efficiency of water use; coping with hydrologic extremes and natural hazards; and the integrated management of water, vegetation, soils and sediments. The declaration also recommended that consideration be given to establishing an international forum that focuses on integrated watershed management including land use and human activities that impact water.

It is not so easy to accomplish and solving the key elements mentioned above for the next generation of watershed management programs, however, it is the time to establish the actual research framework and do act depending on it for the next generation of watershed management issues.

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Water harvesting techniques for sustainable water resources management in catchments area

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Abstract Available quantity and quality of water resources in catchments area has been deteriorated, yet the management pertaining water resources has not been done in a proper way. Water harvesting techniques are alternative by which the water resources can be maintained to cope with the sustainable use of water resources in catchments area. We reviewed experiences of Indonesia in managing water resources in some of catchments area to come up with the recommendation of best practices of water resources management in general and particularly water harvesting techniques. Despite the available fresh water (15,500 m^3 $capita^{-1}$ $year^{-1}$) is more than double of the world available fresh water (600 m^3 $capita^{-1}$ $year^{-1}$), but its distribution is varies. In Java Island for example, where the population reaches to a number of 65% of the total population of Indonesia, but the water only available for 4.5% of the total national water availability. The fact that the available water of about 30,569.2 million m^3 $year^{-1}$ in Java are not enough to cover the need and will be a deficit water in this island at least till 2015. The available water is also fluctuated during wet and dry seasons. For instance, the flow of Cimanuk River (West Java) is recorded as much as 600 m^3 $second^{-1}$ during the wet season, but only 20 m^3 $second^{-1}$ in the dry season. How to manage water in the area with water surplus and deficit is a crucial question to be answer. Water harvesting is becoming very important to cope with sustainable management of water resources. There are different techniques of water harvesting that have been successfully applied as part of water resources management in catchments area in Indonesia. Channel reservoir, on-farm reservoir or "Embung", infiltration ditches, infiltration well, water harvesting dikes, etc. Channel reservoir with cascade system is one of many rainfall and runoff harvesting techniques, which has been proven to be an effective method to reduce peak runoff, extend the time response to runoff generation and to some extend to increase available water for irrigation during the dry season. In Cibogo micro catchment in West Java for example, river flow can be reduced as much as 63% after construction of 2 channel reservoirs with cashcade system and also delay response time of the river flow up to 1 hour. This two important points are very significant to reduce the risk of flood in the down stream areas where the cities are generally situated. On-farm reservoir has also been applied by farmers for supporting their farming to extend cropping. Other water harvesting techniques such as infiltration ditches, infiltration wells, dams, water harvestinmg dikes are also discussed in this paper.

Keyword water harvesting techniques, water resources management, channel reservoir, Embung, catchments area

INTRODUCTION

Water is a crucial need for human in many aspects of live such as agriculture, domestic, industry, municipal, etc. Yet, its availability for those particular needs is depleted due to change in environmental condition pertaining water and to some extend to the increase of water requirement. In addition, there is a significant change of the water status and it's dynamic during wet and dry seasons. It is well known that the need of water is always hampered due to the limited availability during drought period (dry season), while flood frequently and intensely occurs in the wet season.

World Water Forum II in Denhaag, the Netherlands on March 2000 projected that Indonesia has facing water crisis problem on 2025, which due to inefficient water use and water resources management. The magnitude and distribution of water scarcity increase with time, while rapid growth of population and the demand of water to cover human needs have come up with pressure to the available water. The water from the public services such as PDAM has provided the domestic need of the community especially in the city, but it seems not enough to cover whole requirement. The use of groundwater by pumping has becoming popular leading to deplete groundwater level and allowing the salt water intrusion from the sea. In addition, farmers in the irrigated areas have facing a difficulty in accessing irrigation water due to the depletion of the amount of water in the canal. During the wet season, flood frequently occurs and the intensity increases during the last 2 decades. It is very rare that people are aware with water conservation. Further understanding and knowledge gained from the experiences on water harvesting is also lack.

The effort to collect water for completing the need and the use of water in efficient ways is becoming very urgent. Water harvesting techniques are promoted to be introduced to community for handling the water scarcity and disaster due to flood. Collected water from direct rainfall and runoff will be very valuable for covering the needs. Water harvesting may also increase recharge of the groundwater leading to increase groundwater storage. This is the reason why water harvesting techniques is important for sustaining water resources management. The paper is addressed to discuss water harvesting techniques and their role in sustaining water resources management.

WATER RESOURCES IN INDONESIA

Current Status of Water Resources

Indonesia is the fifth rich countries in annual renewable water resources following Brazil, Russia, Canada and United State of America, which has 2838 km^3/yr (Table 1) as it was estimated in www.worldwater.org/data 20062007 as it was recited from FAO (1999). Unfortunately this amount of water is not well distributed all over the country. In Java island, for example, where the population reaches to a number of 65% of the total population of Indonesia, but the water only available for 4.5% of the total national water availability or about 30,569.2 million m^3/year. Unbalance distribution of water over the country consequently addresses to surplus and deficit water as described in Table 2. Papua is the island having the biggest amount of available water and predicted will not have a deficit at least till 2015. Despite the number is not as high as in Papua, deficit will also not happen in Sumatra, Kalimantan, Maluku and West Nusa Tenggara. It is not only fresh surface water such as those stored up in the lakes, rivers, dams, depression areas, water storages etc., groundwater, brackish water, salty sea water are also available. Two third of the country area is covered by sea water. Unfortunately, the amount of available water decreases due to several reasons, one is prior to impact of extreme climate condition. Global and local climate change affects much on the current water resources status. The water stored in the dams, for example, has already declined as the capacity of the dam and the rainfall intensity and pattern have changed (Figure 1).

Table 1 Top ten rich countries in annual renewable water resources.

Country	Annual Renewable Water Resources (km^3/yr)	Year of Estimate	Source of Estimate
Brazil	8233.0	2000	FAO (2000)
Russia	4498.0	1997	Goscomstat, USSR, 1989; FAO (1997)
Canada	3300.0	1985	Pearse, P. H., Bertrand, F., MacLaren, J. W. (1985)
USA	3069.0	1985	United States Geological Survey
Indonesia	2838.0	1999	FAO (1999)
China	2829.6	1999	FAO (1999)
Colombia	2132.0	2000	FAO (2000)
Peru	1913.0	2000	FAO (2000)
India	1907.8	1999	FAO (1999)
Congo (Zaire)	1283.0	2001	Margat, J./OSS (2001)

Source: http://www.worldwater.org/data20062007

Table 2 Available and demand of water in Indonesia.

Islands	Available Water	Water Demands (Million m^3/yr)			Surplus/Deficit (Million m^3/yr)		
	(Million m^3/yr)	1995	2000	2015	1995	2000	2015
Sumatra	111,077.7	19,164.8	25,297.5	49,583.2	91,912.9	85,780.2	61,494.5
Java	30,569.2	62,927.0	83,378.2	164,672.0	-32,357.8	-52,809.0	-134,102.8
Kalimantan	140,005.6	5,111.3	8,203.6	23,093.3	134,894.3	131,802.0	116,912.3
Sulawesi	34,787.6	15,257.0	25,555.5	77,305.3	19,530.6	9,232.1	-42,517.7
Bali	1,067.3	2,574.4	8,589.5	28,719.0	-1,507.1	-7,531.2	-27,651.7
West Nusa Tenggara	3,508.6	1,628.6	1,832.2	2,519.3	1,880.0	1,676.4	989.3
East Nusa Tenggara	4,251.2	1,736.2	2,908.1	8,797.1	2,515.0	1,343.1	-4,545.9
Maluku	15,457.7	235.7	305.2	575.4	15,222.0	15,152.5	14,882.3
Papua	350,589.7	128.3	283.4	1,310.6	350,461.4	350,306.3	349,279.1
Total	691,317.6	110,762.3	158,367.2	358,596.2	584,553.3	536,960.4	336,763.4

Source : Sjarief (2003) as recited from Sutopo, Kompas 27/03/2003.

Lost of water in catchments area is also major determination of water status in Indonesia. It is much affected by factors which significantly determine the capacity of the catchments to conserve rainfall and minimize lost of water through runoff. The major factors determining the lost of water are (a) rapid growth of land use change, (b) increase the degraded (critical) land, (c) increase the distribution of degraded watershed, and (d) other factors affecting the change of hydrological function of the

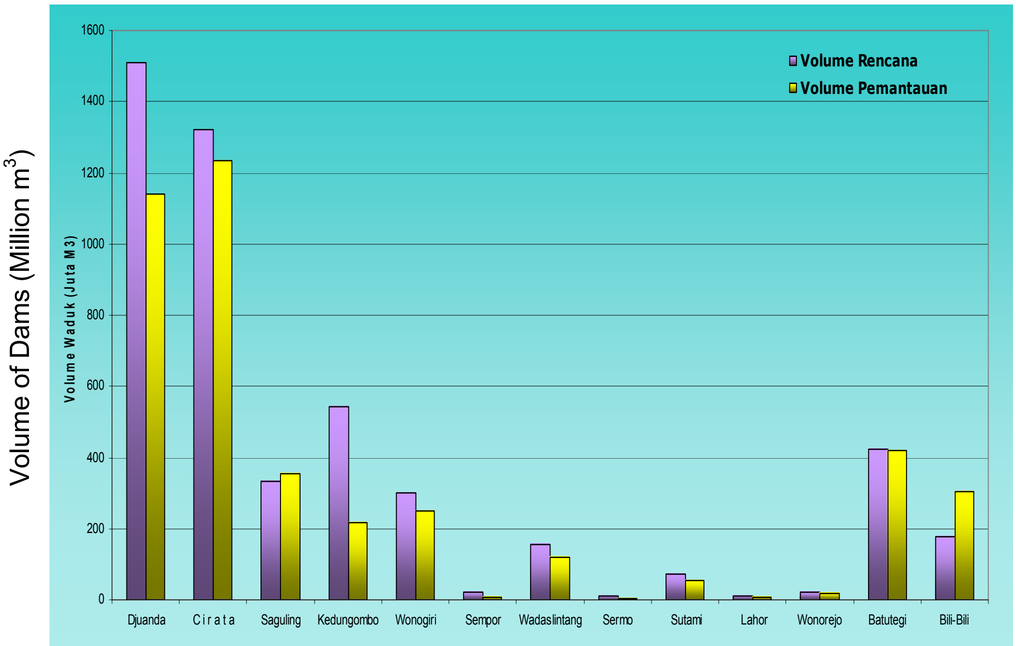

Fig. 1 Available water in the major dams in Indonesia.
Source: PJT II in Subagyono and Surmaini (2007).

watershed. It has been recorded that the critical land in the country has been rapidly developed as it has been as large as 13.1 million ha in 1984 become 51.3 million ha in 2002. Wide spread distribution of the critical land is also factor that must be taken into account in the evaluating the status of water resources in the catchments. It has been recorded as many as 22 critical watersheds in 1984 become 59 critical watersheds in 1998. In addition, other factors determining the hydrological function of watershed such as incorrect land clearing and land management systems, deforestation and over exploitation of water resources in the catchments influence the water resources status.

Water resources status of the country is also believed to be deteriorated due to the impact of climate extreme. Volume of water during the period of El-Nino and La-Nina is fluctuated and varies from season to season. This leads to the change of available water stored in the dams. Figure 2 depicts the distinct of available water in the major dams in Java as affected by the extreme climate events. During La-Nina event, the stored water in the dams exceeds the volume of water in the normal years. In contrast, water scarcity is almost the major phenomenon that has been facing by community in every occasion to cover their need for domestic, industry, agriculture etc. In addition, the volume of available water fluctuates from season to season, where it will be enough water in the wet season but in the dry season.

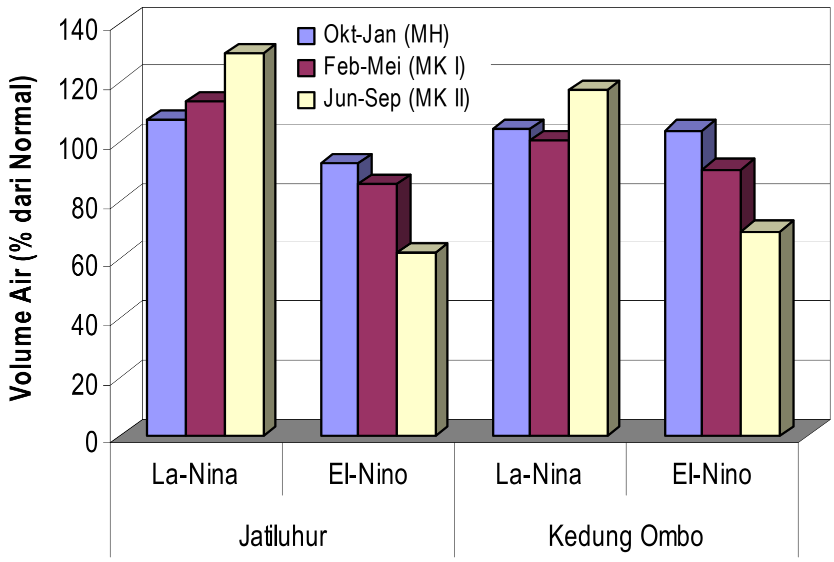

Fig. 2 Average of volume of water at the main water storage in Java during La-Nina, El-Nino, and normal years. WS: wet season, DS: dry season. Source: Las et al. (1999) with modification.

Water Resources Management

Management pertaining water resources is addressed to control a balance between the availability of water and the water requirements. The availability of water is much determined by the hydrological cycle spatially and temporally, while the water requirements often increase in amount and varies uses. Integrated water resources management is urgently to be implemented with aimed to improve community welfare. Figure 3 shows the water resource management concept involving the analysis of balance between the water availability and water requirements.

Despite many aspects of water resources management are significant to be done, but the present paper is addressed to the water harvesting for sustainable water resources management. Since the hydrologic cycle has been changed due to several phenomena such as climate change, catchments degradation as well as over exploitation of water resources, the availability of water resources has been deteriorated quantitatively and qualitatively. An impact of those phenomena is that the appearance of water scarcity in many aspect of lives.

As extreme climate has frequently occurred with increase in its intensity, the pressure to water resources is growing. Inter-annual climate variability in the form of drought and flood (generally those are termed as El-Nino and La-Nina respectively) occurred more frequently and caused much damage. These phenomena have been well understood as the global phenomena. In addition, seasonal variation has also occurred for rainfall, which is characterized by the variability in increasing and decreasing rainfall in the Indian and Pacific oceans. Water resources are often deteriorated by these phenomena leading to lose its available quantitatively and qualitatively.

Land conversion in the watershed system is also the major issues that cause deterioration of the hydrological function of a watershed in Indonesia. The present of

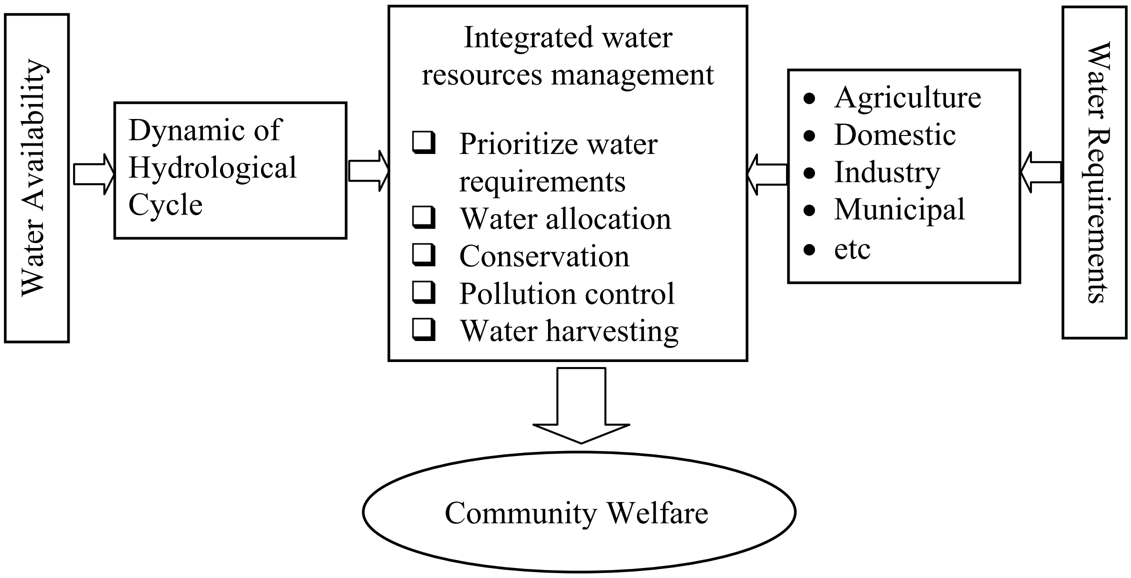

Fig. 3 Diagram of integrated water resources management concept.

critical land, deforestation in the catchments area and other causes of change in watershed function are the major factors causing high surface runoff. The fact that water deficit has increased in the water scarce areas and the available water has decreased in the surplus areas. Reduce in the number of water reservoirs in many watersheds is a proven of the change of hydrological function of the watershed.

The magnitude of vulnerability of water resources to extreme climate should be identified and delineated to address the methodology and approaches to cope with. Adaptation to extreme climate events will be a strategy to sustain the available water resources. Combating to water scarcity during El-Nino event is a key to promote available water resources through water harvesting techniques. Water management is also addressed to use water in efficient ways. Combating the water scarcity and promoting appropriate water management strategies and to some extend developing climate information system to strengthen climate prediction are the best options.

WATER HARVESTING FOR AVAILABLE WATER RESOURCES

Water harvesting has been developed by local community since they did their business to cultivate their land for many uses including agriculture. In Indonesia, many local wisdoms regarding water harvesting are the fact that people have already aware with water for their sustainable business pertaining water. In the recent decade when people have already been aware the deterioration of water they took efforts to obtain water to cover their needs. One of the efforts is water harvesting.

Significance of Water Harvesting

Water harvesting is a technique by which the water can be collected either surface or sub-surface to store up during wet period and used during dry period by applying a proper technique such as channel reservoir, on-farm reservoir, infiltration ditches, infiltration well, check dams, water harvesting dike etc. The water harvesting is addressed and very significance for several objectives including (a) increase recharge groundwater, (b) increase base flow, (c) reduce peak runoff, (d) reduce the risk of flood in down stream areas, (e) extend the time response to runoff generation, and (f) increase available water for irrigation and other uses (domestic, industry, municipal, etc).

Water Harvesting Techniques

Many techniques have been used by various beneficiaries to harvest and store water including (a) channel reservoir, (b) on-farm reservoir (local name of Embung), (c) infiltration ditches, (d) check dams, (e) infiltration well (local name of Sumur Resapan), and (d) water harvesting dikes.

Chanel reservoir

Channel reservoir is a water harvesting technique to store water in the stream channel aimed to support irrigation for agriculture. In Indonesia, it has been widely developed and spread up over the irrigated agriculture areas. An example is those applied in Cibogo micro catchment, West Java. In this micro catchment 2 channel reservoirs have been constructed with a capacity of 300 m^3 and 800 m^3 situated at the elevation of 910 and 950 m asl respectively. The first channel reservoir was constructed to collect water and sediment, while the second one was to collect water and sediment as well as distributing water for irrigation of agricultural land. Both channel reservoirs can collect water from the area of 125 ha, where the collected water was used to irrigate the area of 26 ha through the distribution of water from second channel reservoir. The channel reservoir that have been constructed is depicted in Figure 4.

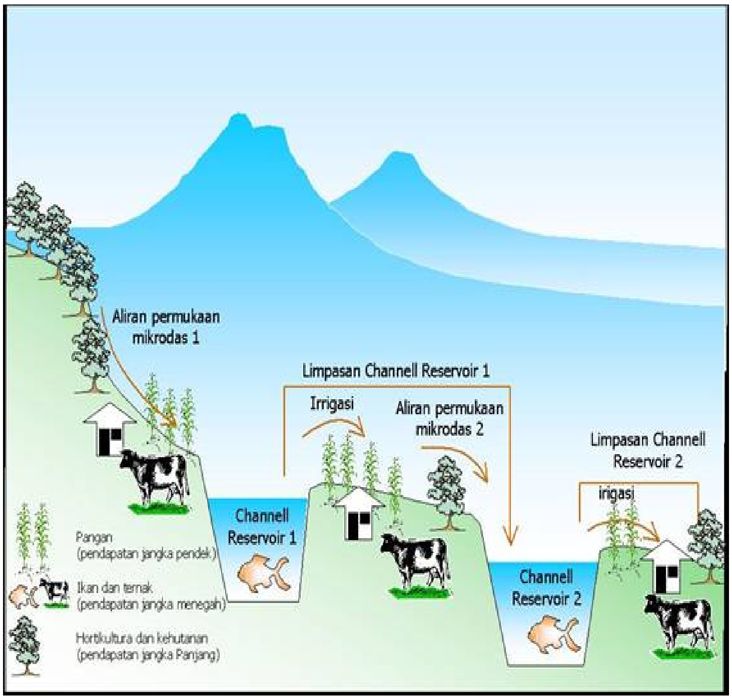

Fig. 4 Channel reservoir for water harvesting and irrigation purposes in Cibogo micro catchment, West Java.

Channel reservoir can also reduce flow of the stream or river from upstream to the downstream areas. Consequently, it may also provide a positive impact on flood reduction in the downstream areas. In the catchment studied, river flow can be reduced as much as 63% after construction of 2 dams (channel reservoirs) with cashcade system (Figure 5). In addition both dams can also delay response time of the river flow up to 1 hour. This two important points are very significant to reduce the risk of flood in the down stream areas where the cities are generally situated.

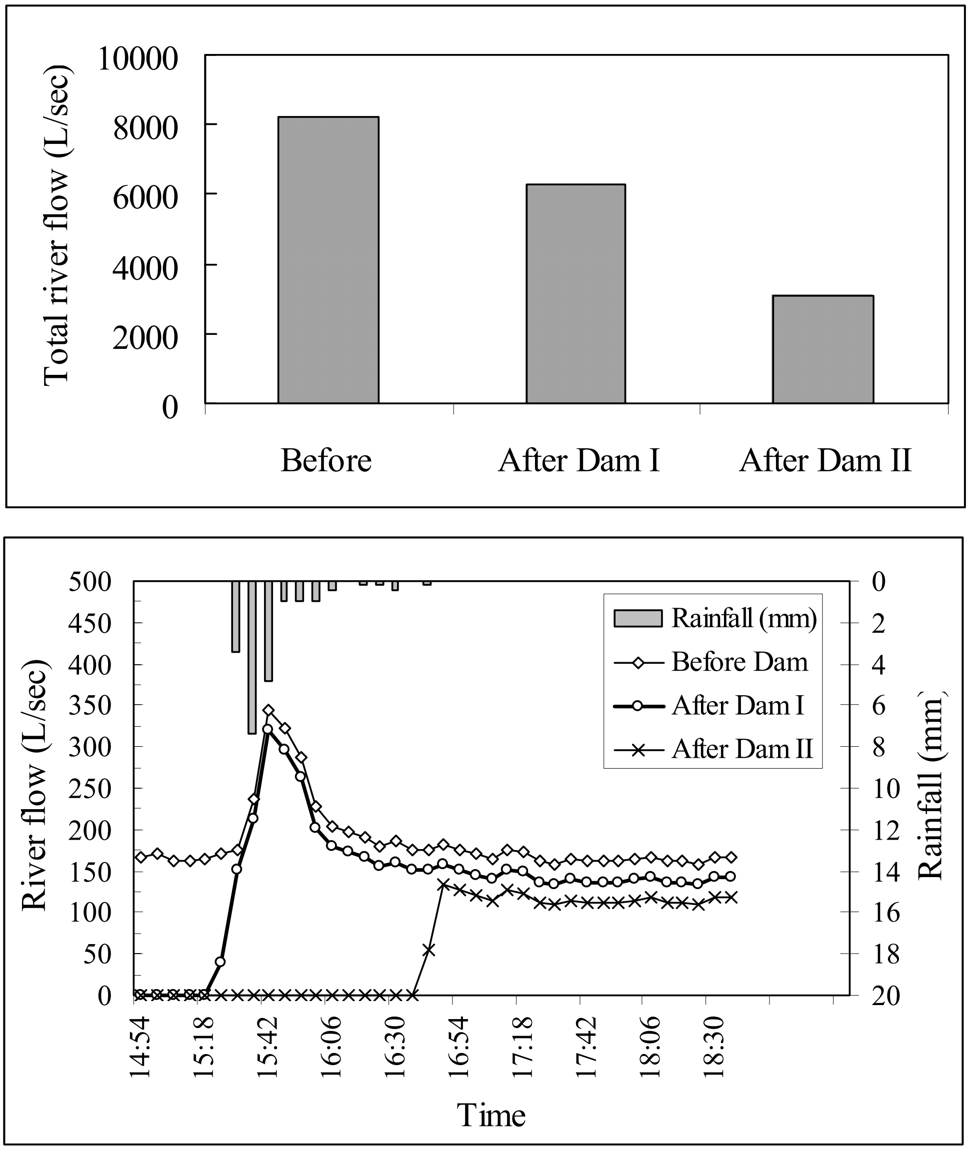

Fig. 5 River flow reduction as an impact of the construction of dams (channel reservoirs). Source: Subagyono *et al*. (2006).

The harvested water during the rainy season can be used to supply water for agricultural areas and domestic uses during the dry season. Since water should be distributed for different uses, water sharing is becoming important to be implemented to overcome a conflict. To do so, the available water capacity and the amount of water for each use need to be identified and quantified.

The total amount of water can be quantified for an area of 125 ha under the mean annual rainfall of 3.340 mm is 4,175,000 m^3 per year. Some of this available water will be loss trough percolation, runoff, evapotranspiration and interception by crops canopy, while the rest is becoming available water for varies uses. It was observed during August and September 2005, that water yields were respectively 10,821 and 14,789 m^3.

Sawiyo (unpublished), reported that the amount of water needed for agriculture was 147,019.0 m^3 per year, as much as 51,051 m^3 per year for domestic use and 182m^3 per year for livestock (Figure 6). There are 7 different cropping patterns have been applied in the studied catchment, i.e. 1) Carrot – Carrot –Carrot; 2) Carrot – Carrot – Chilli; 3) Carrot – Buncis – Tomato; 4) Cabage – Carrot – Cabage; 5) Carrot – Carrot – Cabage; 6) Cabage –Tomato – Buncis and 7) Multiple cropping of those pattern with Banana. The water for domestic use is covering the need for 550 people, while that for livestock is covering for 100 cattle and others.

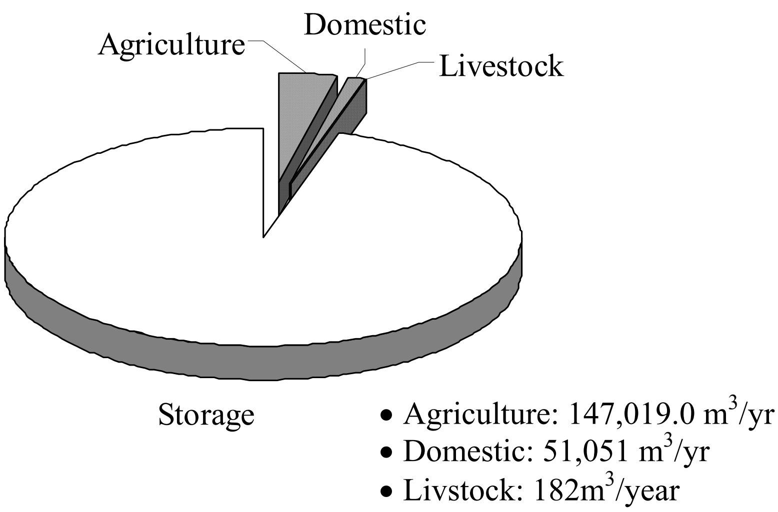

Fig. 6 Water availability at Cibogo micro catchment and the annual use for agriculture, domestic and livestock. Source: Sawiyo (unpublished).

On-farm reservoir (Embung)

Other water harvesting technique is a farm reservoir, the local term is “Embung” (Figure 7). This water reservoir can be used to collect water during wet season and to use for irrigation during dry season. An example can be taken from the experience where “Embung” had been developed to support dry land farming system in Selopamioro, Bantul, Yogyakarta. It had been reported by Irawan et al. (1999), mini water reservoir with a dimension of 7 m x 2.5 m x 3 m and capacity about 52.5 m^3 can contribute to the increase of rainfed rice production up to 176%, production increased from 4,230 kg to 11,700 kg (Table 3). The cultivated area used for this mini water pond was not more than 7% of the total cultivated area.

Fig. 7 On-farm reservoir (Embung) prototype to store water for supporting agricultural irrigation.

Table 3 Effect of mini water reservoir on cropping pattern and crops production in rainfed and dry land areas in Selopamioro, Bantul, Yogyakarta.

Indicator at each land use types	Without mini water pond	With mini water pond
Rainfed		
• Cropping pattern	Rice – fallow	Rice – Tobacco – Maize
• Production (Kg)	4,230	11,700
Dry land		
• Cropping pattern	Peanut – Cassava	Peanut – Maize – Cassava/Vegetables
• Production (Kg)	3,545	4,300 – 6,260

Source: Irawan *et al*. (1999). * Conversion of farming yields based on market price.

Several benefits can be gain from this water harvesting technique using the on-farm water reservoir i.e. (a) runoff and rainfall harvesting, (b) store water during wet season and use in dry season, (c) collect sediment, and (d) support farming irrigation. However, the limitation of implementing this water harvesting technique is that farmers have to spend part of their land for this on-farm reservoir. This needs institutional building which will facilitate collaboration among the farmers in using part of the land for on-farm reservoir, otherwise the implementation of this technology will not be sustained.

Infiltration ditch

Infiltration ditch (Figure 8) is also a technique to store and restore water which also very valuable to support supplemental irrigation for farming. This technique can be used to (a) collect surface runoff, (b) contribute to recharge groundwater, and (c) source of irrigation water. Although this technique is addressed to collect water and allowing irrigation for crops, but other important role of this technique is that it can contribute to groundwater recharge. Since the dimension is smaller than on-farm reservoir, this technique has better prospect to develop.

Fig. 8 Infiltration ditch used for supporting supplemental irrigation for union farming.

Dams

Dam (Figure 9) is also a water harvesting technique with a dimension of much bigger than other techniques. The capacity to store large volume of water is typical for this technique leading to have more functions such as (a) water harvesting, (b) flow reduction, (c) water supply for irrigation, domestic and other uses, and (d) hydro-electric power.

Fig. 9 Dam for water harvesting and hydro-electric power.

Infiltration well

Infiltration well (Figure 10), in local term named as Sumur Resapan, is a water harvesting technique set up mainly for (a) collecting rain water, (b) groundwater recharge, (c) reduce runoff and (d) flood control. Not all areas are reliable to construct the infiltration well unless the area of settlement, area with soil permeability of 2 cm/hr, area with groundwater table of 1.5 m. The infiltration well may have capacity of 1, 2, 4, 6, 8 or 10 m^3 with various shape of square or round.

Many urban areas all over the world face a problem of lowering groundwater table leading to dry out shallow aquifer. It is critical to recover this lowering groundwater table by increasing the rate and distribution of recharge. The infiltration well has been a technique that has been implemented to meet the need.

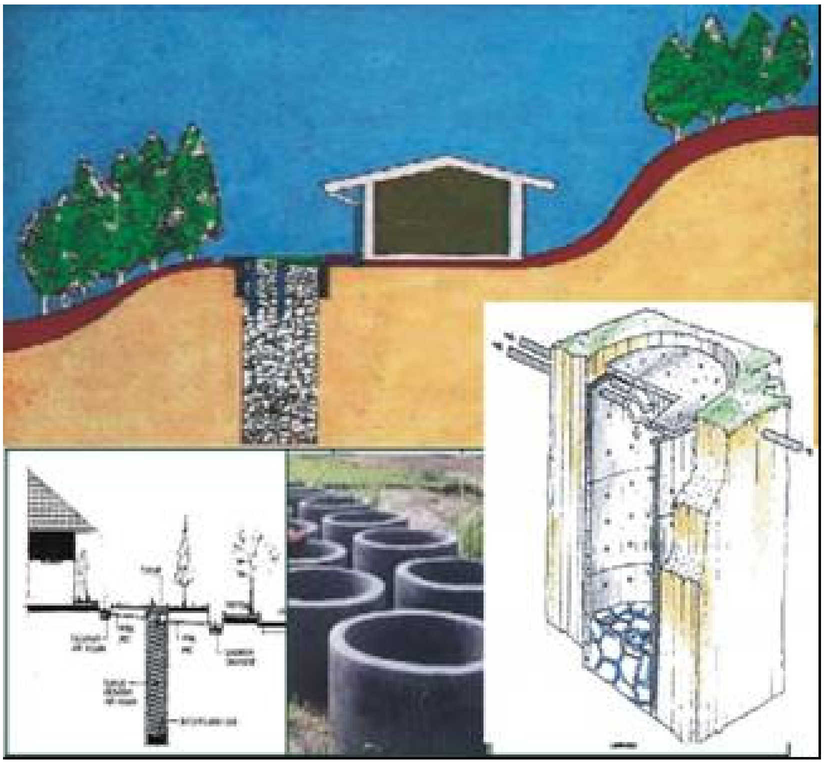

Fig. 10 Prototype of infiltration well used for increase groundwater recharge.

CONCLUSIONS

The significance of water harvesting for water resources management will meet a satisfactory impact if the water harvesting has been correctly and sustainably implemented by community. Water harvesting strategy and techniques are needed to be formulated to meet local specific approaches. Institutional building concerning water harvesting and water resources management is becoming key factor for success. Channel reservoirs, on-farm reservoirs, infiltration ditches, infiltration wells, dams, and water harvesting dikes are techniques may be implemented for sustaining water resources and water resources management.

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Nitrogen and oxygen isotope measurements of nitrate to survey the sources and transformation of nitrogen loads in rivers

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Abstract This paper reviews the studies on evaluation of river environments in terms of water pollution, ecosystem disturbances, excess nutrient (nitrogen) loads, and developments in the isotopic measurements of nitrate and present an update and future perspectives regarding the application of nitrate isotopes to river nutrient assessments. Then, we present the advantages of simultaneous measurement of the nitrogen and oxygen isotopes of nitrate in streamwaters. Dual isotope measurement has recently been used to identify the sources and paths of nitrogen loading in several stream systems. The most recently developed high-resolution denitrifier method is a promising tool with which to investigate the detailed spatial and temporal variation and mechanisms of nitrogen loading and transformation in rivers.

Key words nitrate, $\delta^{15}N$, $\delta^{18}O$, river environment, nutrient status, environmental assessment

INTRODUCTION

Although nitrogen is an essential nutrient in various biomes and ecosystems, excess nitrogen can act as a pollutant, seriously disturbing natural ecosystems. Atmospheric deposition is a major pathway for the loading of anthropogenic inorganic nitrogen into terrestrial ecosystems (Galloway et al. 1995; Galloway and Cowling 2002). In addition, excess nitrogen fertilizer and wastewater discharged from farms, livestock facilities, and residential areas are major direct inputs of nitrogen into aquatic ecosystems. These often constitute non-point sources of nitrogen loading into river systems. Excess nitrate (NO_3^-) and ammonium (NH_4^+) loads often cause the eutrophication of rivers, lakes, and reservoirs, accompanied by extreme algal blooms (Reynolds and Descy 1996).

A load factor method can be often used to estimate practical loads, although there are many uncertainties in the calculation of load factors for various land uses. In general, the nitrogen load in rivers is affect by both terrestrial factors (e.g., hydrology, geomorphology, and land use) as sources and in-stream biogeochemical processes. To estimate the load from each land use and elucidate the in-stream biogeochemical processes in river systems, mass balance investigations use the concentrations of various nitrogen compounds and discharge rate. In addition, models have been developed to describe these mass balances (Allan 1995; Kalff 2001; Ohte et al. 2007).

The isotope components of nitrogen compounds constitute a powerful resource that can provide more detailed insight into the nitrogen dynamics in a catchment; they can reduce uncertainty in a mass balance model performance because they can be used to trace the nitrogen sources and sinks and to retrieve the transformation processes. The $\delta^{15}N$ of some nitrogen compounds reflects their source, isotopic fractionation resulting from physical and chemical reactions, and biological reactions and functions such as uptake, nitrification, denitrification, and assimilation in food webs. In addition to them, the stable isotopes of associated elements of nitrogen compounds, such as the ^{18}O of NO_3^-, can also be used as a powerful tracer. For instance, the $\delta^{18}O$ value of NO_3^- differs significantly between one generated biologically in soils and/or aquatic system and one formed atmospheric chemically in upper-air (Kendall 1998).

Therefore, the spatial and temporal variation in isotope signals, especially multi isotope signatures, can provide insightful information on nitrogen cycles, biological usage, and exports from ecosystems. This is also meaning that the isotope tracer techniques have been useful for an assessment on the anthropogenic nitrogen pollution in rivers and lakes. As we mentioned later, the applications of multi isotope technique to trace the nitrogen transport and transformation have been conducted for scientific researches since 1990's. The multi isotope tracer techniques, however, has not often applied on an operational assessments and survey of river environments.

The purposes of this paper are to briefly review the developments in the isotopic measurements of nitrate and present an update of this field. We then introduce the novel techniques for simultaneous measurements of nitrogen and oxygen isotopes of dissolved nitrate that has recently been developed and improved, and demonstrate a case study surveying the river nutrient status in a Japanese watershed using this method. Then, we address the future perspectives regarding the application of nitrate isotopes to river nutrient assessments.

METHODS FOR THE ISOTOPE MEASUREMENT OF NITRATE

The ammonium distillation method was generally used to measure the nitrogen isotopes of nitrate in natural waters before the mid-1990s. This method involves the reduction of nitrate to ammonium, which is distilled and concentrated as an ammonium sulphate salt and then combusted to produce nitrogen gas for isotope measurement using a mass spectrometer. Sigman et al. (1997) modified the ammonium diffusion method, which was formerly used for the tracer-level measurements of nitrogen isotope ratio. Dissolved nitrate is reduced to ammonium in a closed bottle, and the gaseous ammonia is trapped by a glass fiber filter impregnated with acid solution. The nitrogen isotope ratio of the ammonium ions on the filter is measured using an isotope ratio mass spectrometer connected to an elemental analyser (EA-IRMS) through a continuous flow system. This method is more accurate and facilitates sample preparation.

In the 2000s, Silva et al. (2000) proposed a new method using ion exchange resin. In this method, nitrate ions in a water sample are concentrated by adsorption on an anion exchange column. The adsorbed nitrate ions are removed from the resin by adding hydrochloric acid. This solution is neutralized using silver oxide, and the precipitated silver nitrate is extracted by freeze dehydration. Finally, the $\delta^{15}N$ of the silver nitrate is measured using an EA-IRMS. It is relatively easy to prepare a sample for isotope measurements using this method. Moreover, the concentration of the sample using an ion exchange column in the field after collection eliminates the need to bring a large volume of water to the laboratory. Chang et al. (1999) proposed a method to determine the $\delta^{18}O$ of nitrate in fresh water using an ion exchange column.

Compared to these methods, the new "denitrifier method," which can be used to measure the $\delta^{15}N$ and $\delta^{18}O$ of nitrate simultaneously, has many advantages (Sigman et al. 2001; Casciotti et al. 2002). The dissolved nitrate is reduced in a glass vial by denitrifying bacteria, which cannot reduce nitrous oxides gas (N_2O) to nitrogen gas (N_2). The nitrous oxide gas is input to a mass spectrometer for isotopic measurement through a continuous flow system. To produce N_2O gas from dissolved NO_3^- in a sample, the other reducing methods have also recently been developing using UV light or spongy cadmium for the reaction from NO_3^- to NO_2^- and using azide or hydroxylamine for NO_2^- -N_2O reduction (McIlvin and Altabet 2005).

The most critical advantage of the denitrifier method is that the required sample volume is less than 1/100 of that needed by the previous method. This feature is critically important for samples that contain a very small amount of nitrate. This method has made it possible to measure nitrate isotopes in samples such as ice cores, soil pore water, and even plant xylem water that could not be analysed using other methods. The denitrifier method can also used for seawater because it is insensitive to the ionic strength of the solution. Moreover, whereas dissolved organic nitrogen can act as contaminant in nitrogen isotope measurements using the previous method, it does not interfere with measurements performed using the denitrifier method because the bacteria only denitrify nitrate. The sample preparation is markedly faster than that for the previous method. However, this method has several weaknesses: the storage and maintenance of the denitrifying bacteria requires some special techniques, and the presence of ^{17}O in nitrate molecules, especially in rainwater, interferes with the $\delta^{15}N$ measurement of N_2O. The denitrifier method cannot be used to measure the $\delta^{15}N$ of nitrate and nitrite separately, but measures the total $\delta^{15}N$ and $\delta^{18}O$ of nitrate and nitrite in the solution. Therefore, when the nitrite concentration is high relative to nitrate, it is necessary to check the measured $\delta^{15}N$ and $\delta^{18}O$ values carefully. To measure $\delta^{18}O$, it is better to measure nitrate and nitrite separately because it is important to determine whether nitrate or nitrite is the dominant supplier of ^{18}O.

ADVANTAGES OF THE SIMULTANEOUS MEASUREMENT IN NITRATE $\delta^{15}N$ AND $\delta^{18}O$

Advantages of the Simultaneous Measurement of Nitrate $\delta^{15}N$ and $\delta^{18}O$

In temperate climates, nitrate is a relatively mobile form of nitrogen in soil systems because of its solubility and inabsorbability, and it is the major form of dissolved nitrogen in streams and rivers, except in heavily reduced aquatic systems. Therefore, nitrate tracing is a useful approach by which to understand nutrient dynamics and transport in aquatic systems in temperate climate. However, there is no remarkable difference in the $\delta^{15}N$ of nitrate between precipitation and fertilizer (Kendall 1998). In addition, the $\delta^{15}N$ of soil water nitrate is often similar to that of precipitation.

As mentioned previously, the $\delta^{18}O$ measurement of nitrate was developed in the late 1980s and has been used to revealed new characteristics of nitrate in various environments (Amberger and Schmidt 1987; Voerkelius 1990; Aravena et al. 1993). Kendall compiled the $\delta^{15}N$ and $\delta^{18}O$ of nitrate in precipitation, soil water, river and lake water, and groundwater from these studies and showed that the range of $\delta^{18}O$ in precipitation is very large compared to that in other sources of water. Possible

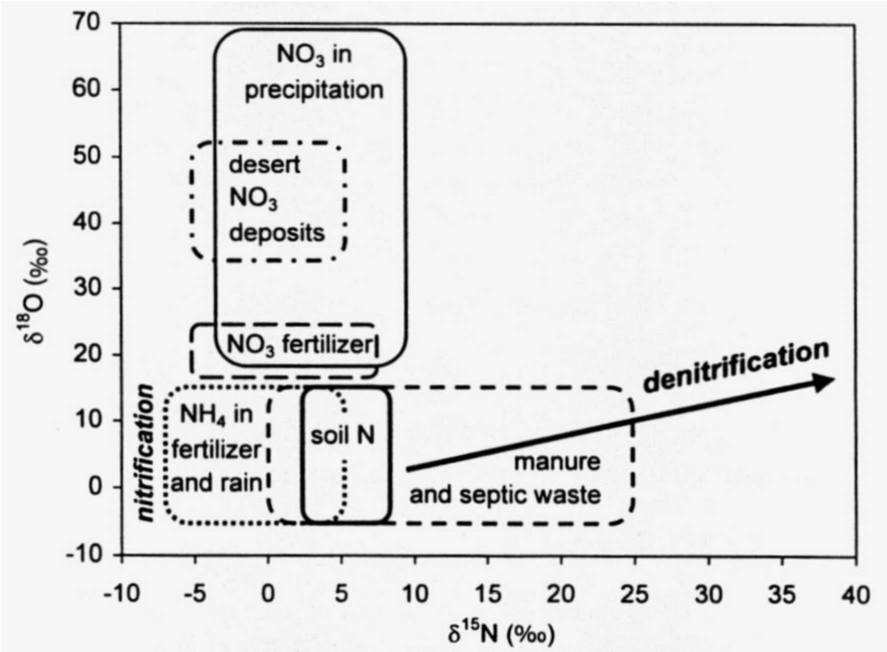

Fig. 1 Schematic diagrams of typical ranges of $\delta^{15}N$ and $\delta^{18}O$ values of nitrate from various sources (presented originally in Figure 1) drawn by Kendall (1998). Nitrification of ammonium and/or organic-N in fertilizer, precipitation, and organic waste can produce a large range of d values. Soil waters tend to have higher NO_3-$\delta^{18}O$ values, and a lager range of NO_3-$\delta^{18}O$ values, than groundwaters because of the higher $\delta^{18}O$ values of O_2 and/or H_2O in soils.

mechanisms for this large range in $\delta^{18}O$ involve various geochemical and atmospheric processes. Fractionation associated with nitrate formation occurs during thunderstorms, in the incomplete combustion of fossil fuels in power plants and vehicle exhaust, and in atmospheric photochemical reactions. A likely mechanism for the high $\delta^{18}O$ of nitrate is the reaction of ozone (O_3) with nitrogen gas (N_2), producing NO_x (Wahlen and Yoshinari 1985; Krankowsky et al. 1995).

Using this characteristic of $\delta^{18}O$, the nitrate supplied by precipitation can be distinguished from the nitrate produced by microbial activity in soils or added to soil as fertilizer, whereas this separation cannot be made using $\delta^{15}N$. Kendall (1998) summarized previous reports, and proposed a diagram of the $\delta^{15}N$ and $\delta^{18}O$ ranges of major sources of nitrate (Fig. 1). Denitrification causes both the $\delta^{15}N$ and $\delta^{18}O$ of the residual nitrate to increase as the nitrate concentration decreases. Therefore, this diagram is useful to examine not only the origins of nitrate, but also the strengths of the processes involved in nitrogen transformation.

Studies have evaluated the contribution of atmospheric nitrate to stream nitrate in North America using the $\delta^{18}O$ of nitrate (Williard et al. 2001; Burns and Kendall 2002; Campbell et al. 2002). The samples are typically collected at intervals of several weeks or months, and the seasonal changes in the contribution of atmospheric nitrate to stream nitrate are discussed.

Ohte et al. (2004) measured both the $\delta^{15}N$ and $\delta^{18}O$ of stream nitrate at a very high frequency using the denitrifier method (Fig. 2). The greatest advantage of the denitrifier method is its ability to measure the $\delta^{15}N$ and $\delta^{18}O$ of nitrate simultaneously and its high throughput. Fluctuations in the concentration and $\delta^{18}O$ of nitrate in streams indicated that atmospheric nitrate made a strong, direct contribution during the early snowmelt period in a forested watershed in the northeast United States as a result of highly concentrated nitrate stored in the snow pack during the winter. Another advantage of the denitrifier method is that it requires only a small amount of nitrate (several tens of nanomoles). Thus, Elliott et al. (2007) were able to measure the $\delta^{15}N$ and $\delta^{18}O$ of rainwater collected from across the United States and showed clear geographical patterns depending on the NO_x source such as stationary fuel combustion at electric power plants and vehicular emissions.

CASE STUDY ON TWO RIVERS IN THE LAKE BIWA BASIN

We have been evaluating the "environmental health" of a river basin in central Japan since 2003 using multiple isotope techniques. In this extensive investigation, we have

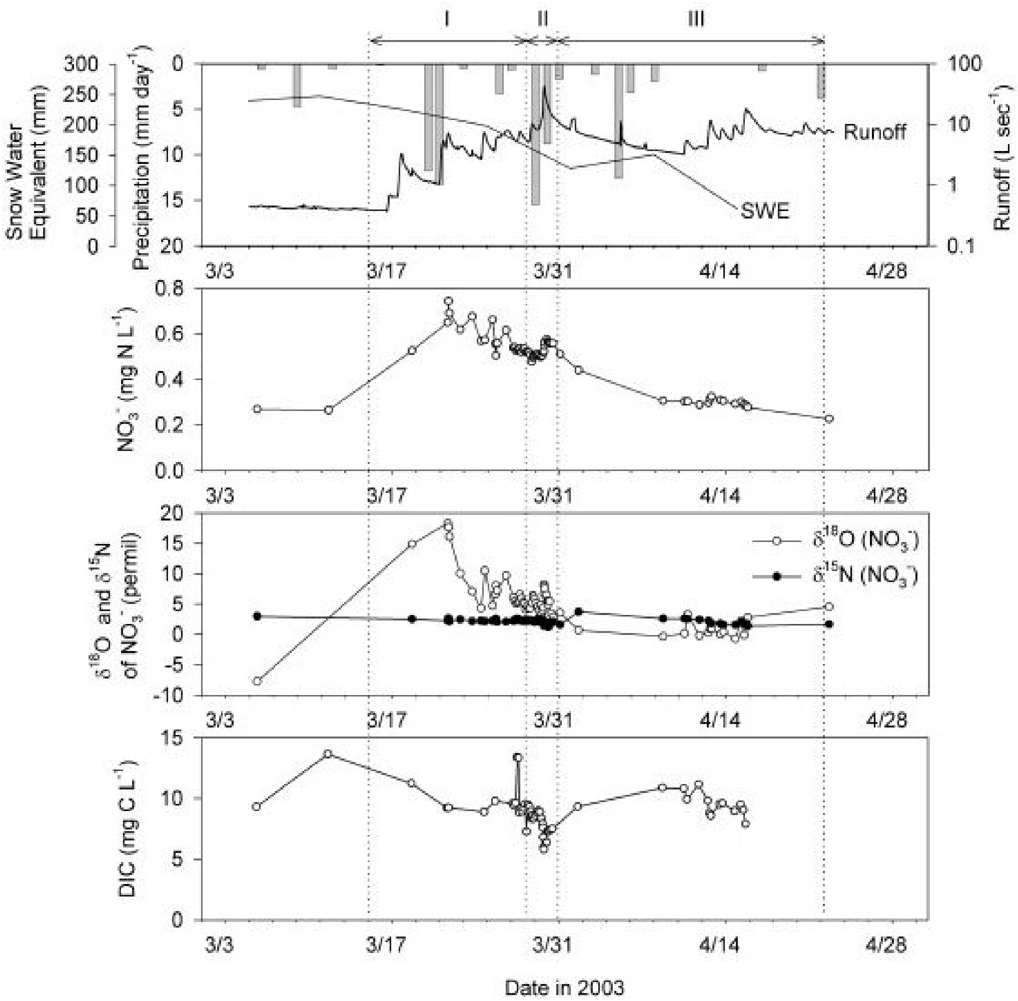

Fig. 2 Precipitation, runoff, snow water equivalent (SWE), nitrate concentration, $\delta^{18}O$ and $\delta^{15}N$ of nitrate, and DIC concentration during snowmelt 2003. Phase I was the early snow melt, 16 to 29 March, Phase II was the peak flow period, 29 to 31 March, and Phase III was 1 to 22 April. Precipitation includes rain and snow that fell in this period (Modified from Ohte et al. (2004)).

examined 32 rivers in the Lake Biwa basin. For these rivers, we are attempting to find useful isotope information to describe the water quality (pollution status), nutrient conditions, and ecological status and to propose indexes for integrated "health" evaluation. Here, we introduce some new findings from this project and state our perspectives for the future.

Lake Biwa is the largest freshwater lake in Japan (670 km^2). It has more than 32 inflow rivers, but only one outflow river. The Lake Biwa basin is located in the warm temperate climate region. Details of its climatic and hydrological features are described by Suzuki and Fukushima (1985). The basin has forests in the northern and western parts, agricultural land (mainly rice paddies) in the eastern part, and urban areas in the southern part.

We have investigated the changes in the $\delta^{15}N$ and $\delta^{18}O$ of nitrate between rivers with and without anthropogenic nitrogen inputs (Fig. 3). The Yasu River basin contains an agricultural region that consists mainly of paddies and residential areas in the middle to downstream parts, whereas forest dominates the Ado River basin. The nitrate

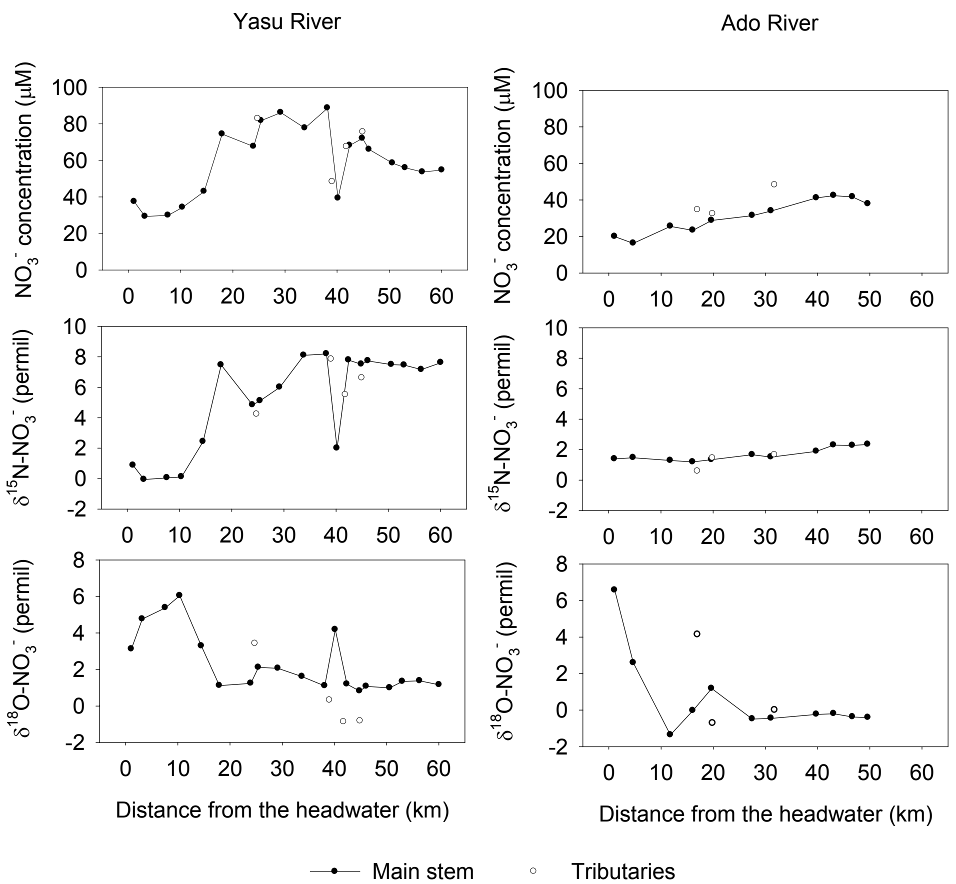

Fig. 3 Comparison of the changes in the concentration, δ15N, and δ18O of nitrate between rivers with (Yasu River) and without anthropogenic nitrogen inputs (Ado River). The Yasu River basin contains an agricultural region that consists mainly of paddies and residential areas in the middle to downstream parts, whereas forest dominates the Ado River basin (Nagata et al., in preparation).

concentration and $\delta^{15}N$ increased slightly downstream in the Ado River, whereas both increased dramatically in middle portion of the Yasu River. The $\delta^{15}N$ of organic matter also increased in the riverbed sediments. This clearly indicates the marked effects of the inflow of wastewater from agricultural fields and residential areas. In contrast, the $\delta^{18}O$ of nitrate in the Yasu River was higher (+4 to +7‰) upstream and decreased to +1 to +2‰ as the $\delta^{15}N$ increased downstream. This phenomenon may be explained in the same manner as the relatively high $\delta^{18}O$ in river water from forest-oriented watersheds. It may be reasonable for stream water in upstream forested catchments in relatively steep mountainous areas to contain more atmospheric nitrate than that drained from agricultural or urbanized regions because forested watersheds act as natural storage systems.

FUTURE PERSPECTIVES

Although conventional monitoring of discharge, water quality, and biotic communities of rivers has generated useful diagnostic information, this approach is costly.

Expensive instruments and intensive maintenance and labour are required to obtain high-quality data with sufficient spatiotemporal resolution. Despite the high cost, these data alone provide little information on the sources of water and materials, and even less on the geochemical and ecosystem processes that control material cycling and affect food webs. The use of multiple stable isotope ratios of water, nutrients, and organisms provides integrated diagnostic information in a timely, cost-effective fashion and overcomes the serious deficiencies of conventional approaches. One great advantage of the multiple stable isotope approach is that it combines the benefits of robust principles and a methodology that has already been developed in individual disciplines, including watershed hydrology, geochemistry, and community ecology. In addition, recent advances in mass spectrometry allow high-throughput measurements at a much lower cost than previously. The intensive monitoring of multiple environmental isotopes has become a practical option to be implemented in watershed diagnosis.

We expect that the carefully coordinated monitoring of multiple stable isotope ratios in a given watershed can provide comprehensive information on: the sources and flow paths of water and nutrients, especially nitrogen compounds; various metabolic parameters of ecosystems; and the energy base and food web structure of aquatic communities, depending on the watershed type and scale. These new data should supplement conventional data and aid in their interpretation to greatly enhance the ability to detect human-induced changes, as well as the incipient of changes of complex watershed systems.

Although in this paper we did not discuss the use of stable isotopes for food web analysis in river ecosystems, food web analysis is an indispensable part of any integrated assessment of ecosystem health, together with an investigation of nutrient dynamics using isotope tracing. For instance, Cabana and Rasmussen (1996) conducted a study based on this concept and developed a conceptual model to express the spatial distribution of the $\delta^{15}N$ of various aquatic organisms in rivers and lakes as a function of population density, which is a proxy of the strength of anthropogenic nitrogen loads. In addition, the preliminary results of our project suggest that the $^{15}N/^{14}N$ ratios of sediments and fish are an excellent indicator of the perturbation of the nitrogen cycling and food webs of river communities. In future, efforts to establish protocols for the integrated evaluation of river ecosystem health are needed. These protocols will involve the use of multiple isotope signatures both to trace nutrient cycles and to examine the food web structure.

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Groundwater management issues in the Greater Jakarta area, Indonesia

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Abstract The Greater Jakarta occupies the northern zone of Java Island and the elevations of this plain vary from 0 to 1,000 m above sea level. It is one of the most developed basins in Indonesia and is located between 106° 33'-107° E longitude and 5° 48' 30"- 6° 10' 30" S latitude covering an area of about 652 km². The population of Jakarta at present is around 7.5 millions. As the water which is supplied by surface water only covers 30% of water demand, people are harvesting the available groundwater in the basin, which has already caused a negative impact on these resources itself both quantity and quality. The changing environment as consequence of the development has also brought undesirable effects to the quantity of groundwater. Therefore, the proper groundwater management of this area should be identified

Keyword Jakarta groundwater basin, environment, water quality, water quantity, groundwater management issues

INTRODUCTION

Since the beginning of the 20th century, groundwater from the Greater Jakarta Basin has been used for drinking water and other water resources purposes. Unfortunately, groundwater use is increasing year by year and some problems are threatening this fragile aquifer system. It has influenced either quality or quantity of groundwater. In the field, it is identified by groundwater level decline and the occurrence water intrusion in some parts of the basin.

The dependency of industry on groundwater is one of the constraints faced by groundwater management. This dependency is associated with the lack of infrastructure provided by the government. According to the most recent data, the amount of clean surface water that supplied to the industrial sector was only about 3.5 million m3 in 2003, which is just 1% of the volume required by industry. This means that almost all water required by the industrial sector comes from groundwater.

Another factor influencing the scarcity of groundwater is the condition of groundwater recharge area. Groundwater recharge can be interpreted as the addition to the groundwater from an external area to the saturated water column. Generally, groundwater is replenished from rainfall, rivers and human intervention such as an artificial recharge well or lake. One of the main factors influencing groundwater depletion is significant changes of the land cover from natural terrain to the developed areas, especially in the recharge area.

The groundwater management problem in the Jakarta Basin has many dimensions, one of them is to provide alternative source of water for industrial use. Looking at the groundwater control mechanism in the Jakarta Basin, licensing is still considered the main tool for controlling groundwater abstraction. This mechanism would not work with the bare minimum awareness of the stakeholders about the importance of groundwater conservation and weak law enforcement and monitoring. The fact is that in the Jakarta Basin, many unregistered deep wells still have been found. There are no incentives such as tax compensation for industries that recycle water. The result is that many industries are not interested in water conservation, making it extremely difficult to control groundwater extraction in the Jakarta Basin. The failure of water utilities to supply raw water and to extend the coverage area has also become a trigger for the groundwater problems. Industry still depends on groundwater, and since industries are self-regulating, groundwater control becomes difficult. The future challenge for groundwater management is to alter the mechanism of water provision that currently applies.

The increase of groundwater exploitation in Jakarta Groundwater Basin has already caused a negative impact on these resources itself both quantity and quality. In addition the changing environment as consequence of the development has also brought undesirable effects to the quantity of groundwater. In order to manage the groundwater potential in its optimal capacity, it is important to identify exactly where the recharge area take place and which quantities are involved.

THE STUDY AREA

The Greater Jakarta is the capital city of Republic of Indonesia. It occupies the northern zone of Java Island that comprises low hilly areas of folded Tertiary strata, and Quaternary coastal lowlands bordering the Java Sea (Fig.1). Two quaternary formations and three young tertiary formations act as groundwater aquifers zone and one quaternary formation act as an aquitard. Some older formations present as basement of the basin. The elevations of this plain vary from 0 to 1,000 m above sea

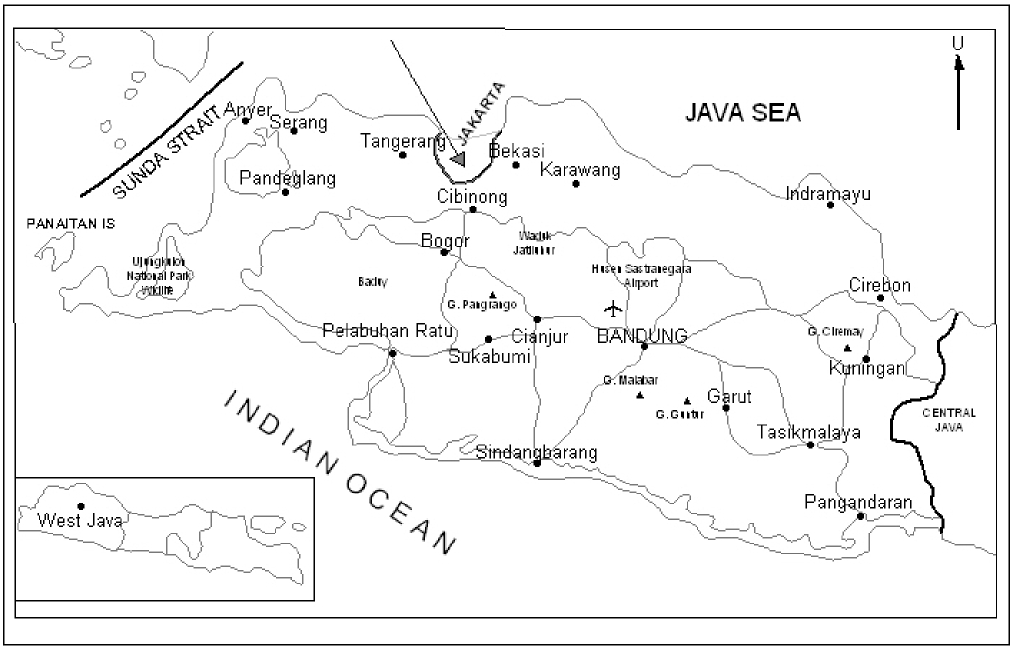

Fig. 1 Location map of the Greater Jakarta. It is the Capital City of Republic of Indonesia and located in the coastal area of Java Island.

level. It is one of the most developed basins in Indonesia and is located between 106° 33'-107° E longitude and 5° 48' 30"-6° 10' 30" S latitude covering an area of about 652 km². It has a humid tropical climate with annual rainfall varying between 1,500 - 2,500 mm and is influenced by the monsoons.

The population of Jakarta at present is around 7.5 millions (Jakarta Local Government Website, 2007) and the population density is presented on Table 1. It represents the official number of population actually living in the Greater Jakarta area. The reality which is faced by Jakarta is that many people who are working in Jakarta during the daytime are living in the adjacent cities i.e., Bogor, Depok, Tanggerang, and Bekasi (Bodetabek Area). Since the operation of the Jakarta - Bandung Highway, some people living in the cities of Purwakarta and Bandung have also become commuters. This circumstance has caused the population of Jakarta to increase up to 10 or 11 millions during the weekdays. It is obvious that urbanization has increased the water demand in this area. As the drinking water which is supplied by surface water only covers 30% of water demand, people are harvesting the available groundwater in the basin. In Jakarta Groundwater Basin, the use of groundwater has greatly accelerated conforming to the rise in its population and the development of industrial sector, which consume a relatively huge amount of water.

Table 1 Population density in Jakarta area.

District of identified area	Population density (people/km^2)
South of Jakarta	11,676
East of Jakarta	11,157
Central of Jakarta	18,746
West of Jakarta	12,426
North of Jakarta	8,267
Seribu Island	1,616
Population density average	11,272

Source: Statistical Local Office of Greater Jakarta, 2003.

GEOLOGICAL SETTING

According to Engelen and Kloosterman (1996), structurally, the Jakarta groundwater basin is part of the so called a Northern Zone comprising the low hilly areas of folded Tertiary strata, and coastal lowlands bordering the Java Sea.

Geologically, the study area is dominated by quaternary sediment and, unconformably, the base of the aquifer system is formed by impermeable Miocene sediments which are cropping out at the southern boundary, which were known as Tanggerang High in the west, Depok High in the middle and Rengasdengklok High in the east. They acted as the southern basin boundary. The basin fill, which consist of marine Pliocene and quaternary sand and delta sediments, is up to 300 m thick. Individual sand horizons are typically 1 - 5 m thick and comprise only 20% of the total fill deposits. Silts and clays separate these horizons. Fine sand and silt are very frequent components of these aquifers (Martodjojo, 1984 ; Assegaf, 1998)

In detail, Sudjatmiko et al. (1972), Sundana and Ahmad (1972), Effendi et al. (1974) and Turkandi (1992) differentiated the lithology in this area into some formations and explained as follows (Fig. 2):

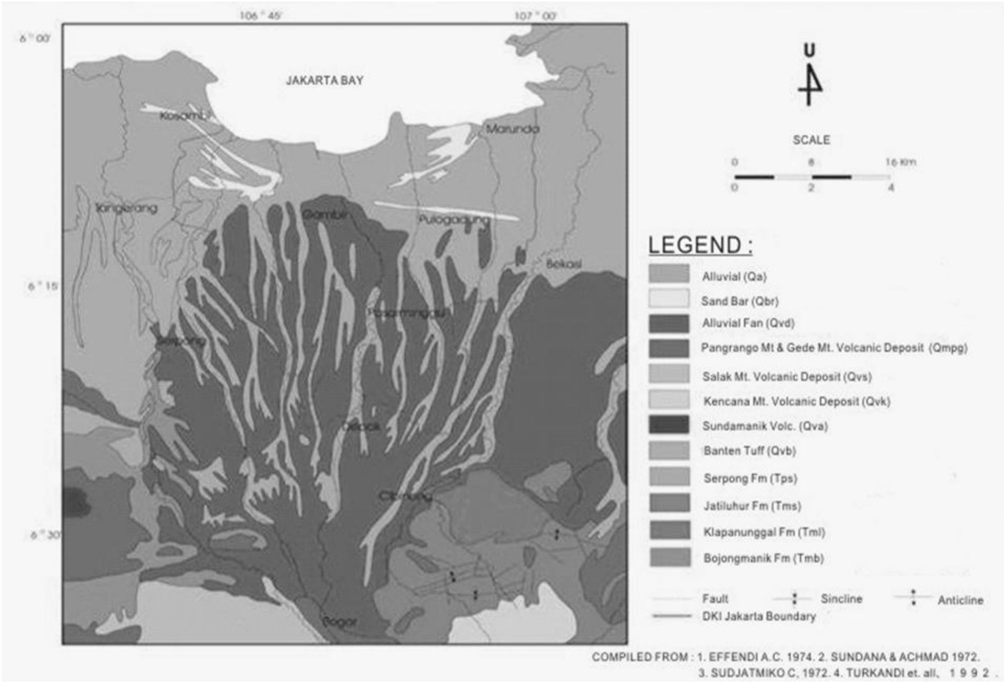

Fig. 2 Geological map of the Greater Jakarta and its surrounding area. At the surface, the lithology is dominated by coastal and deltaic deposits.

a. **Rengganis Formation** consists of fine sandstones and clay stone outcropped in the area of Parungpanjang, Bogor. Un-conformably, this formation is covered by coral limestone, marl, and quartz sandstone.
b. **Bojongmanik Formation** consists of interbedded of sandstone and clay stone, with intercalated limestone.
c. **Genteng Formation** consists of volcanic eruption material such as andesitic breccias and intercalated tuffaceous limestone.
d. **Serpong Formation**, intebedded of conglomerate, sandstone, marl, pumice conglomerate, and tuffacueous pumice.
e. **Coral Limestone**, Holocene age and found in Seribu Island Complex in Jakarta Bay, consist of coral colony, coral fragment, and mollusk shell.

Beside those above lithology, there are found Banten Tuff, young volcanic eruptive material, fan deposits, paleo and recent beach ridge deposits which are deposited parallel to recent coastal line.

MEGACITY GROUNDWATER PROPERTIES

There are 5 main factors that influences the groundwater resources in a mega city as Jakarta i.e., global climate change, population pressure, urbanization, agricultural and industrial activities. It is known that global climate change phenomena have increased the sea water level. It influenced the position of shorelines in some parts of the world, including northern part of Jakarta area that has border with the Java Sea. Like many other cities that located on coastal area, sea water encroached into the land and influenced either surface of groundwater resources. Total of population, urbanization and industrial activities created a pressure to the groundwater resources due to groundwater over-abstraction activity to fulfil their daily needs. The urbanization can also increase the impervious cover, drains, utility lines, backfilled areas, surface flow, point sources for recharge and contamination. The potential impacts of urbanization on groundwater resources are the resources availability and quality degradation. Some impacts of groundwater use on urbanization are infrastructure damage that is caused by the occurrence of land subsidence and infrastructure drainage and uplifted problems. Agricultural has a reciprocal relationship with the groundwater resources as it needs some groundwater resources for growing plants and in the other side, plants can act as the water recharge instrument. Public health condition is very much depending on the groundwater condition as people in Jakarta Area fulfil their water daily need from groundwater. The worse groundwater quality condition the worse public health of the area.

The groundwater in urban area is abstracted from aquifers through dug or drilling wells. Together with surface water, they are used o supply domestic, industrial, and agricultural activities. The waste water from those activities then are treated and used for irrigation or injected back to the aquifers. The urban groundwater quantity is depend on the aquifers direct and in-direct recharge, impermeable covers, artificial replenishment to increase aquifers recharge.

The Groundwater Management

The main threats to groundwater sustainability arise from the steady increase in demand for water and from the increasing use and disposal of chemicals to the land surface. Management is required to avoid serious degradation and there needs to be increased awareness of groundwater at the planning stage, to ensure equity for all stakeholders and most important of all to match water quality to end use. Despite the threats from potentially polluting activities, groundwater is often surprisingly resilient, and water quality over large area of the world remains good. A vital aid to good groundwater management is a well-conceived and properly supported monitoring and surveillance system. For this reason monitoring systems should be periodically reassessed to make sure that they remain capable of informing management decisions so as to afford early warning of degradation and provide valuable time to devise an effective strategy for sustainable management.

Some alternatives to increase the water resources are: increase surface storage; improve groundwater management; water utilization efficiency; and large-scale inter basin water transfers. To improve the groundwater management, the sustainable groundwater management strategy should be employed. This strategy covers long term groundwater resources conservation, groundwater quality protection; change the groundwater resources management paradigm to groundwater as a non renewable resource.

It was recognised that the groundwater problems in recharge area is different with the groundwater problems in discharge area. The main groundwater problem in recharge area is the decreased of groundwater recharge which is caused by land use degradation. This substance can initiate the runoff increased and groundwater storage decreased, and creates flood and drought disasters. Therefore, the recharge area management should be employed appropriately. The main problem in discharge area is the increased groundwater usage for human activities. It causes groundwater table descent and groundwater storage reduction and creates land subsidence, groundwater pollution, and drought disasters. Those problems then lead to flood disaster and groundwater resources crisis. In the discharge area, the things that should be executed are groundwater abstraction management. It is known that for doing the groundwater management, the basin geometry and the cover of recharge and discharge area should be defined first.

JAKARTA GROUNDWATER MANAGEMENT

Jakarta Groundwater Present Condition

Overexploitation of groundwater has become a common issue along the coastal area where good quality groundwater is available. Consequently, many coastal regions in the world experience extensive saltwater intrusion. It is obvious that urbanization has increased the water demand in this area. As the drinking water which is supplied by surface water only covers 30% of water demand, people are harvesting the available groundwater in the basin. In the Jakarta Groundwater Basin, the use of groundwater has greatly accelerated conforming to the rise of its population and the development of the industrial sector, which consumes a relatively huge amount of water. According to the Ghyben-Herzberg model, the natural hydrostatic equilibrium between salt and fresh water can change when a change occurs in the fresh groundwater head pressure. It can occur due to groundwater over- pumpage as it is taking place at the present time in Jakarta. Over-pumpage can also decrease the volume of groundwater and land surface subsidence occurred. The subsurface layer compaction also supports the existence of land subsidence. Geyh and Soefner (1996) reported on the salt water intrusion phenomena in the Jakarta Area. Djaja et.al. (2004) recognized land subsidence phenomenon occurring in some parts of the Jakarta Metropolitan Area. Serious problems of salt water intrusion have affected some coastal cities in Indonesia, including Jakarta. Medan, Surabaya, and Semarang and the size and extent of the intrusion very much depend on the manner of groundwater usage. The initial model was developed by Ghyben in 1888 and Herzberg (1901) and it is known as the Ghyben-Herzberg model which forms the base of the hydrostatic balance between fresh and saline water in a U-shaped tube.

Based on groundwater monitored data of 51 monitoring wells around Jakarta area, it can be concluded that most of water level in Jakarta area of 5 clusters aquifers i.e. 0 - 40 meters, 40 - 95 meters, 95 - 140 meters, 140 - 190 meters, and 190 - 250 meters, were decreased (Fig. 3).

Considering the detrimental impact of land subsidence on building and other infrastructures, a number of researchers carried out investigations on the cause and the rate of subsidence. Most of the land subsidence investigations have been conducted over part of the Jakarta territory. The trend and rate of subsidence is characterized by the condition of the point where the equipments are located.

The estimated subsidence rates during the period Dec.1997 to Sept.2005 are 1 to 10 cm/yr and reach 15-20 cm/yr. The highest rates of land subsidence occur in northwestern Jakarta. The central and north-eastern parts sometimes also show quite high rates of subsidence. These vertical temporal variations however, may still be contaminated by annual/semiannual signal bias that plagues all GPS temporal

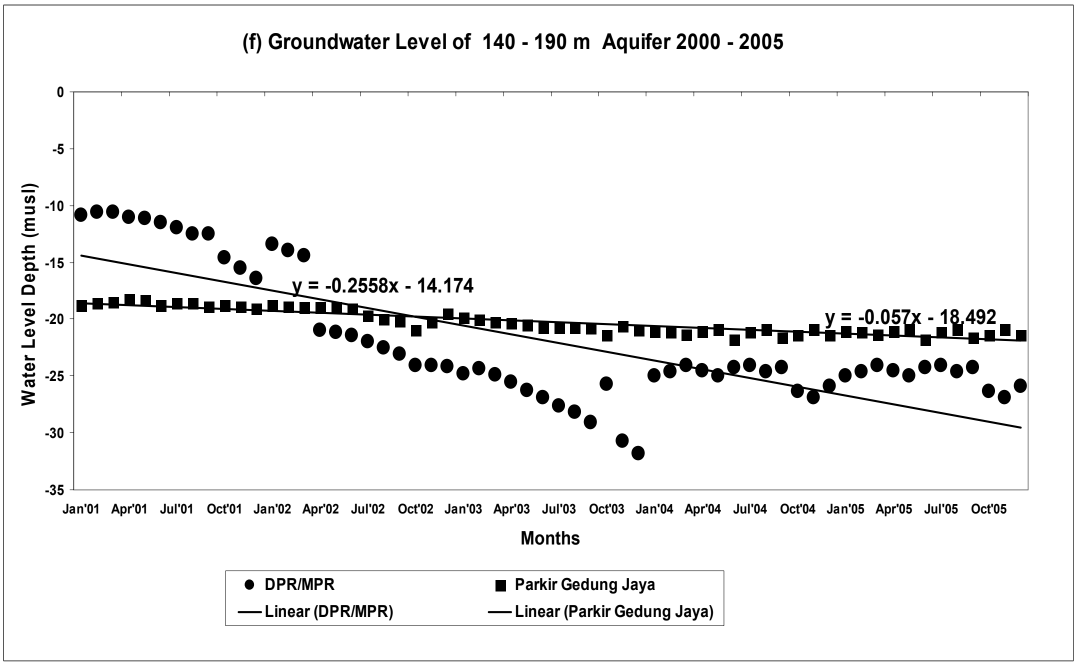

Fig. 3 Groundwater level fluctuations between of 2001- 2006 at some locations in Greater Jakarta area. It is showed that the groundwater tend to decrease.

measurements (Abidin et al., 2007). From the observation period 1982 - 1991, the highest subsidence occurred at Cengkareng (North Jakarta) with a rate of 8.5 cm/year. In the period 1997 -1999, the highest subsidence occurred at Daan Mogot (North-West Jakarta) with a rate of 31.9 cm/year. The rate increase shows that the land subsidence in Jakarta is continuing.

Determination of Recharge and Discharge Area

It is known that the hydrogeology of the Jakarta Basin is a very complex phenomenon. Until now, a good understanding of the hydrogeology of the basin on a regional scale is still not possible, due to lack of systematically sufficient drilling, testing and monitoring data. A collection of the drilling data of additional monitoring boreholes, to establish a closer monitoring network, has made it possible to develop a better understanding of the shallow groundwater flow systems. A chemical analysis of the monitoring well's water samples will assist in recognizing the water quality decrease and interaction between fresh and salt water. Groundwater level monitoring of boreholes will be required to develop an improved understanding of the water table fluctuations, the regional and local impacts of groundwater abstraction and dewatering related to groundwater yield.

Jakarta recharge and discharge area was determined using drainage pattern analysis, wet land area delineation, geological condition, and sub-surface temperature profile. The first three analyses showed the circumstance of Jakarta Basin geometry. It is shown very clearly that the Jakarta Groundwater Basin is not as wide as it is estimated before. The sub-surface temperature data analysis identified the Jakarta groundwater recharge area and direction of water flow inferred from the thermal properties.

There are some studies (Cartwright, 1970; Sakura, 1978 and 1993; and Dim et al, 2000), where temperature data were used to understand the groundwater flow system in a basin. The basic theory is that heat can be transported in a porous medium by way of three processes: conduction, convection, and radiation. The most important groundwater movement process in an aquifer is the convection process, as the convective alteration can cause the groundwater geothermal to increase with increasing depth in the recharge area and decrease in the discharge area (Domenico and Palciauskas, 1973). If it is assumed that the groundwater temperature in the well is equal to the surrounding subsurface temperature, we can get a one-dimensional view of the groundwater distribution by profiling the water temperature in the well. This is most important point for water temperature analysis when compared to other physically based measurements or tracer techniques.

The thermal disturbance that is caused by the advection of subsurface water flow makes thermal analyses suitable for groundwater studies. A number of previous authors (Cartwright, 1970; Parsons, 1970; Boyle and Saleem, 1979; Kilty and Chapman, 1980; Drury, 1984; Woodbury and Smith, 1988; Jobmann and Clauser, 1994) found that thermal signatures of groundwater underscore the fact that various conditions in a flow system can distort isotherms. Subsurface temperature analyses have proven that they can be quite appropriate in tracing and differentiation of the groundwater flow path. Temperature is the best and most reliable tool to establish the depth of groundwater circulation (Mazor, 1997).

The interaction of water with its surroundings generates various natural process, products, and conditions. Flow systems, on the other hand, function as mechanisms of transport and distribution of those effects into regular spatial patterns within the basinal flow domain. One of the results of these natural processes is that water moving through the subsurface can transport matter and heat. Heat transport by moving groundwater is one of the most visible and most well understood geologic processes in the subsurface (Beck et al., 1987; Romijn et al., 1985; Rybach, 1985; Smith and Chapman, 1983). Water can contain and transport heat because of its specific heat capacity.

Subsurface temperature distribution is affected by heat conduction and heat advection due to groundwater flow. There are some hydrological studies in which the groundwater flow system is estimated from subsurface temperature distribution in basins or plains (Uchida et al., 1999; and Sakura, 1993). Based on the results of these studies, it could be concluded that the subsurface temperature in the recharge area is much lower than in the discharge area at the same elevation. Temperature profiles measured in wells show a decreasing temperature gradient with depth in the recharge area and increasing temperature gradient with depth in the discharge area (Taniguchi et al., 1999). The geothermal zone is marked by temperature profile is not subject to seasonal variations and ground water flow perturbs the geothermal gradient by infiltration of relatively cool water in recharge areas and upward flow of relatively warm water in discharge areas which is causing concave upward profiles in recharge areas and convex upward profiles in discharge areas.

Without groundwater flow, the temperature-depth profile has a constant gradient with depth and a stratified thermal regime. Domenico and Palciauskas (1973) analyzed the two dimensional groundwater temperature distributions under condition of regional groundwater flow and found a concave shape for recharge areas where the downward water flux dominates and a convex shape for discharge areas where the upward groundwater flux dominates.

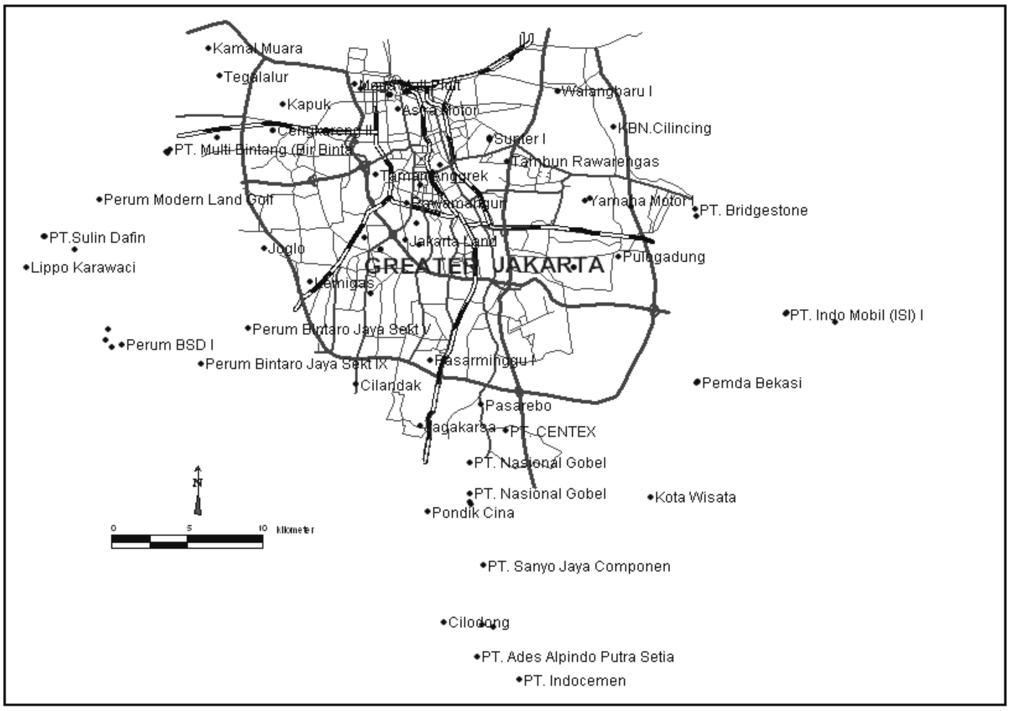

Fig. 4 Monitoring wells location in Greater Jakarta area and its surrounding area.

For this study, the thermal profiles in 51 monitoring wells of various depths (20 – 200 m) around Greater Jakarta area were measured. Measurements were carried out using a digital thermistor thermometer of 0.01 ^{o}C precision and the accuracy is $\pm$ 0.03 ^{o} C which was attached to a 300 m long cable measured the subsurface temperature at 2 m intervals from the static water level to the bottom of the hole. The wells were drilled exclusively to monitor groundwater level and subsidence caused by groundwater withdrawal. They are therefore ideal for thermal studies as they had attained a steady-state thermal condition as the time elapsed since their construction was quite a long period. The groundwater temperature data measurement analysis was plotted on the map and the detailed recharge and discharge area of Jakarta Basin was determined (Fig. 5). It showed that mostly Greater Jakarta Area is occupied by discharge area, while the recharge area located just in the southern part of this area. Facing this reality, the groundwater management in this area must be more concerned to the problems that are discovered within discharge area.

The recharge area of the aquifer at a depth of 40 m below surface is located at the southern part of Jakarta Basin itself, and the water from Bogor area is discharged at the south boundary of Jakarta basin as it is blocked by the Bojongmanik Formation (Depok High). The recharge of the aquifer at a depth of 95 m below surface comes from the S-E and S-W area of the basin, the recharge area of the aquifer at a depth of 140 m below surface is located at the S-E area, while the deepest aquifer is supplied by water from the east.

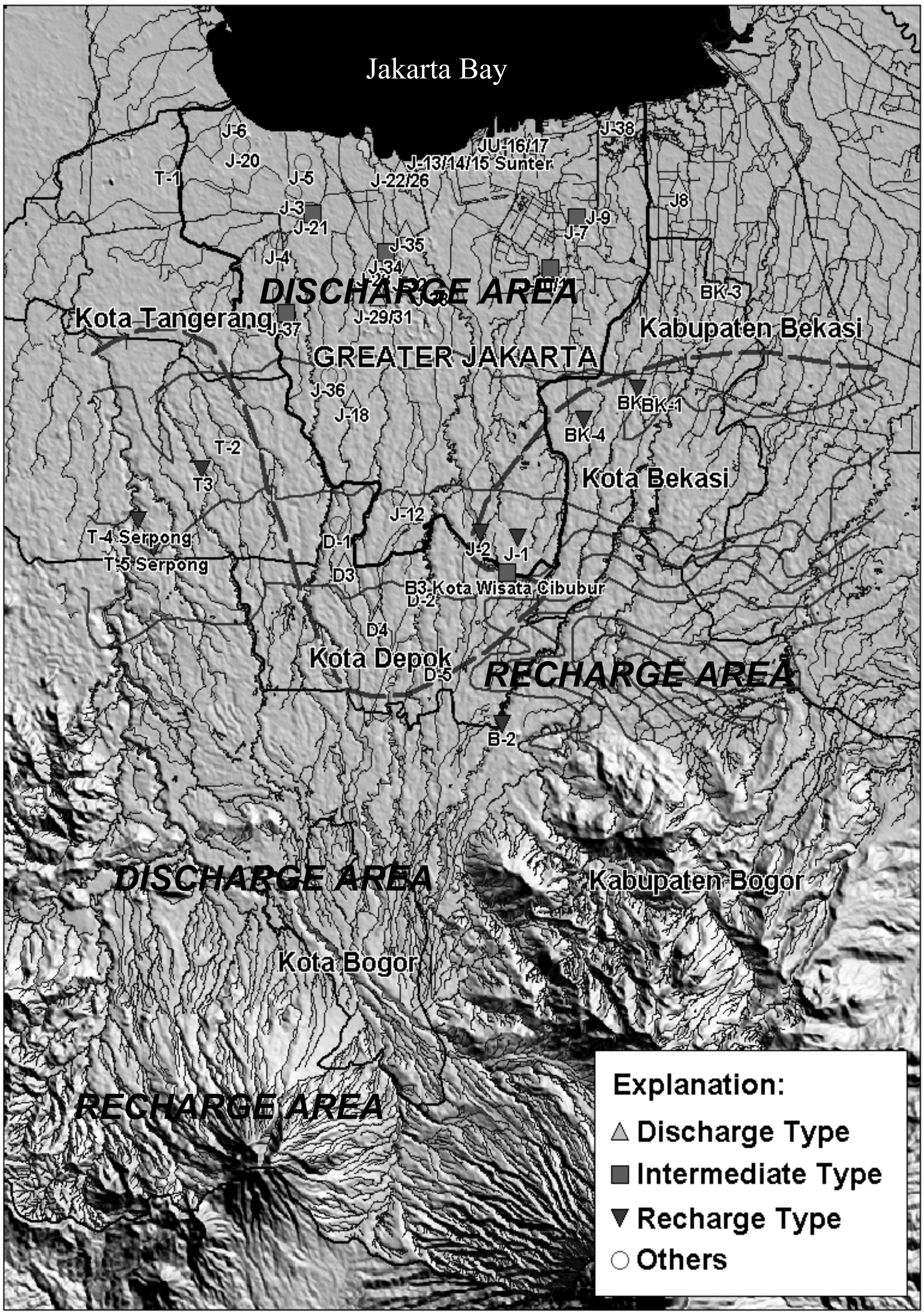

Fig. 5 Recharge and discharge area delineation using sub-surface temperature data analysis and direction of water flow inferred from the thermal properties.

The Groundwater Management in Greater Jakarta Area

Based on the groundwater hazard assessment in Greater Jakarta Area, as the discharge area, the quality hazards that were found are mostly the water pollution of domestic waste and industrial activities. Quantitatively, when groundwater level and reserve decreased, the land-subsidence, flooding and drought disasters, and sea water intrusion were discovered. In the recharge area, southern part of Jakarta, the domestic waste and agricultural activities influenced the groundwater quality condition. The decline of water recharged and groundwater reserve, the increasing run off and reduced of springs debit were encountered in this area. It is recognized that qualitatively the groundwater in Jakarta Area had been disturbed since the recharge area. Therefore, the condition of recharge area must be managed simultaneously with the discharge area.

The groundwater management should cover the two important aspects, i.e., physical and technical aspects, and social and non technical aspects. Physically and technically, for managing groundwater quality, water treatment, waste management, wells monitoring, and groundwater quality modelling should be executed both in Jakarta Greater Area and in recharge area. Groundwater quantity management in recharge area will cover land rehabilitation, re-forestation, springs conservation, artificial recharge and injection wells construction, and recharge area broadening. In Jakarta Area, it will cover wells monitoring, groundwater maximum depletion and abstraction, sustainable groundwater yield determination, groundwater balance and local flow modelling, and water canals construction.

Socially, the groundwater quality management in recharge area and discharge area, Greater Jakarta Area, should cover control of groundwater source conservation zone; socialization of dangerous and environmental friendly substances utilization, groundwater quality basic knowledge. The groundwater quantity management in recharge area will cover the groundwater basic knowledge socialization, built area control, groundwater source conservation zone control, recharge area plan control, and law enforcement. While in discharge area, the discharge area plan control, groundwater abstraction tax, groundwater abstraction control, groundwater condition change monitoring, groundwater basic knowledge and sanitary system socialization, and law enforcement. Scheme of the whole groundwater management issues in Greater Jakarta are presented on Fig. 6.

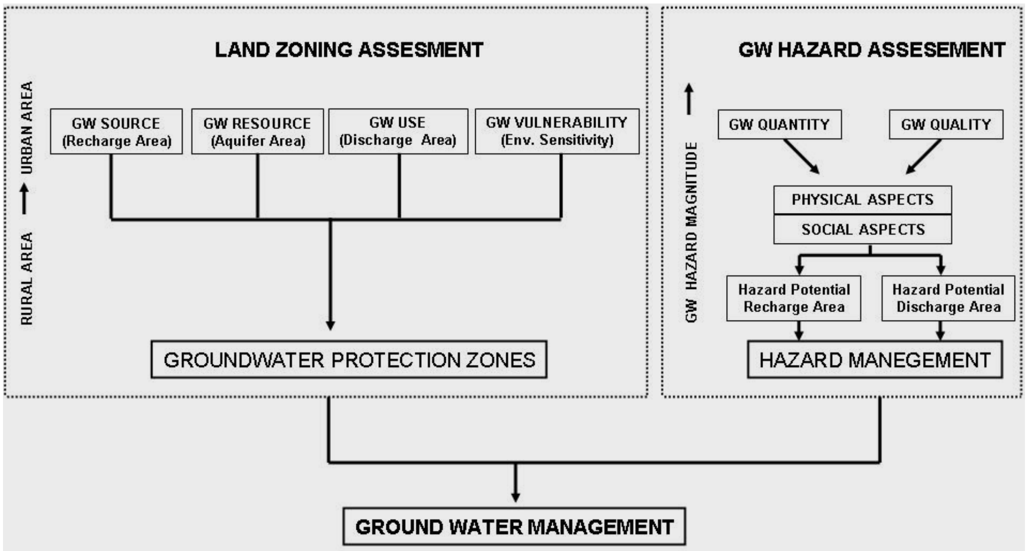

Fig. 6 Scheme of groundwater management in Greater Jakarta area.

CONCLUDING REMARKS

Some remarks concerning the water management in Greater Jakarta area can be indicated, among others are:

1. To improve the groundwater management, the sustainable groundwater management strategy should be employed. This strategy covers long term groundwater resources conservation, groundwater quality protection; change the groundwater resources management paradigm to groundwater as a non renewable resource.
2. Greater Jakarta aea is occupied by discharge area, while the recharge area located j ust in the southern part of this area. Facing this reality, the groundwater management in this area must be more concerned to the problems that are discovered within discharge area.
3. Based on the groundwater hazard assessment in Greater Jakarta area, as the discharge area, the quality hazards that were found are mostly the water pollution of domestic waste and industrial activities.
4. It is recognized that qualitatively the groundwater in Jakarta area had been disturbed since the recharge area. Therefore, the condition of recharge area must be managed simultaneously with the discharge area.
5. The groundwater management should cover the two important aspects, i.e., physical and technical aspects, and social and non technical aspects.

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Hydrometeorological monitoring network of Java Island and hydrologic characteristics of the major river basins

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Abstract Java Island had been known as the most populated island in the world. The population had been doubled in the last four decades to about 128 million people with average population density of about 1, 000 people per sq. km. This high population density accompanied with rapid physical developments in the past decades have created extensive land and forest destructions and causing intensified man-induced natural disasters, such as floods, droughts, forest fires and landslides. The availability of integrated hydrological and meteorological data for the whole territory of Java Island is an opportunity through which research can take advantage in many fields, including development of water management and disaster monitoring. For this reason, we reviewed the hydrometeorological monitoring network of Java Island and the characteristics of the major river basins in this paper.

Key words hydrology, monitoring, characteristic, Java Island

INTRODUCTION

Java Island could be divided into 14 major watersheds i.e. Ciujung-Ciliman, Ciliwung-Cisadane, Cisadea-Cikuningan, Citarum, Cimanuk, Ciwulan, Citanduy, Pemali Comal, Serayu, Jratun Seluna, Progo-Opak-Oyo, Bengawan Solo, K. Brantas, and Pekalen Sampean. Those watersheds are really essential to fill up the requirement for agriculture, industries, electricity power, and domestics of Java citizens. Unfortunately, the water yield of those watersheds decreased in recent years because of climate change impact and population pressure (Amien and Runtunuwu, 2008).

Climate change has already caused the change in rainfall pattern resulting in the shift of the onset of the seasons. The dry season will become longer causing water deficit and possibly drought that reduce planted areas and crop yield. On the other hand the rainy season will become shorter with higher intensity inducing landslide and flood (Meiviana et al., 2004). Dutta and Herath (2004) reported that Indonesia is the third most frequently affected by floods in Asia. Based on data from CRED (2007) in period of 1980-2007, about 34% of all natural disasters is flood that occurred almost in all provinces of Indonesia with direct economic losses about US $ 1.638.050. The worst flood occurred in 2007, when 454.8 km2 of Jakarta were flooded and 590.000 people were evacuated (National Planning Board, 2007). In this last two years alone landslides on island of Java has taken hundreds of life and loss US $ 109.745 of property worth. The major change also was caused by human activities with land cover and land use conversions from vegetated area into non vegetated area, as reported by Isa (2006) that paddy field area in Java Island decreased 50,100 ha per year.

To improve the role of watershed as main water supplier for irrigation, industries, and domestics' requirement, the water resources database system of each watershed with their circumstances are imperative. Based on this system, the water sharing management of each watershed could rearrange in order to minimize the water insecirity impacts.

HYDROMETEOROLOGICAL MONITORING NETWORK OF JAVA ISLAND

Figure 1 shows the present network of hydrometeorological stations of Java Island which managed by IAHRI (Runtunuwu and Las, 2007). There are 74 automatic weather station (AWS) and 23 automatic water level recorder (AWLR) in seven provinces i.e. Lampung, West Java, Centre of Java, DI Yogyakarta, East Nusa Tenggara, East Kalimantan and South-east Sulawesi. In addition, IAHRI has collaboration with other institutions such as BMG, and Ministry of Public Works to collect the meteorological data, as shown in Table 1. It is available upon request to Numeric and Spatial Information System for Agroclimate and Hydrology Laboratory (NSISAH), IAHRI. The data from those stations is at present used in hydrometeorological studies, such as climate forecasting and water yield prediction.

Fig. 1 The location of hydrometeorological stations of Java Island managed by IAHRI.

The main problem in collecting data from other institutions was the variability of kind of data. Each institution designed their observed instrument based on their purposes and budget; therefore, the data were dissimilar in variable, unity, observed period, and structure form. These problems were handled by standardising the climate and hydrology variables as well their unity before put into database system. The availability of the latest data is essential; therefore, online networking for collecting data from other institutions to database system has to develop.

IAHRI develops the water resources information system based on three important aspects; Firstly, one watershed with one database system for one management, in order to accommodate the specific characteristics of each watershed. Secondly, by integrating both tabular and spatial data in one database system due to the variability of input data type; and finally was user friendly.

An example of water resources information system which developed by IAHRI

Table 1 The number of hydrometeorological stations of Java Island recorded by IAHRI.

No	Province	Number of stations
1	DKI Jakarta	4
2	West Java	408
3	Central of Java	636
4	East Java	406
5	D.I. Yogyakarta	77
Total		1 531

was Citarum Water Resources Information System (Kartiwa, et al. 2005) in collaborating with Perum Jasa Tirta II (PJT II). The project was started with characterized the whole input data, such as tabular, vector and image data. The types of those data were awfully varied in observed period and size scale; therefore, reorganizing the data in one database system was imperative. In general, tabular data were watershed characteristics, climate/rainfall, and discharge data that could put into database system by using worksheet form. The spatial data such as administrative boundary, watershed/sub watershed boundary, contour, river, road, and irrigation network that put into the system by digitations technique. The other spatial data was image data such as land cover type distribution that obtained from image satellite processing.

The next step was hydrology modelling development by using programming technology. They were several discharge prediction models could be used, however in Citarum watershed purpose the H2U and GR4J models has been selected. The Hydrogramme Unitaire Universel (H2U) model predicted instantaneous discharges of watershed (Duchesne et al., 1997) with automatic rainfall station while GR4J model (Perrin, 2000) predicted daily discharge of watershed with manual rainfall station only. By running the discharge prediction model, the yield water of Citarum watershed could be calculated. This information was very important for PJT II in order to determine the amount of water supply for irrigated paddy field, industries, and domestics.

Opening Menu of Citarum Water Resources Information System consists of Main Menu, Daily Simulated Discharge, Instantaneous Simulated Discharge, and Observed Data Presentation, Figure 2. Observed presentation menu consists of two windows choice i.e. watershed and reservoir information. Watershed information presented discharge data visualization at outlet, rainfall data, and discharge data debit at weir and climate data. Map based on GIS presented on main menu is interactive, showed position of observed discharge station, rainfall, climate and dam; reservoir; administrative boundary; watershed/sub watershed boundary; contour, river, road, irrigation network, and information of land use change, as shown in Figure 3.

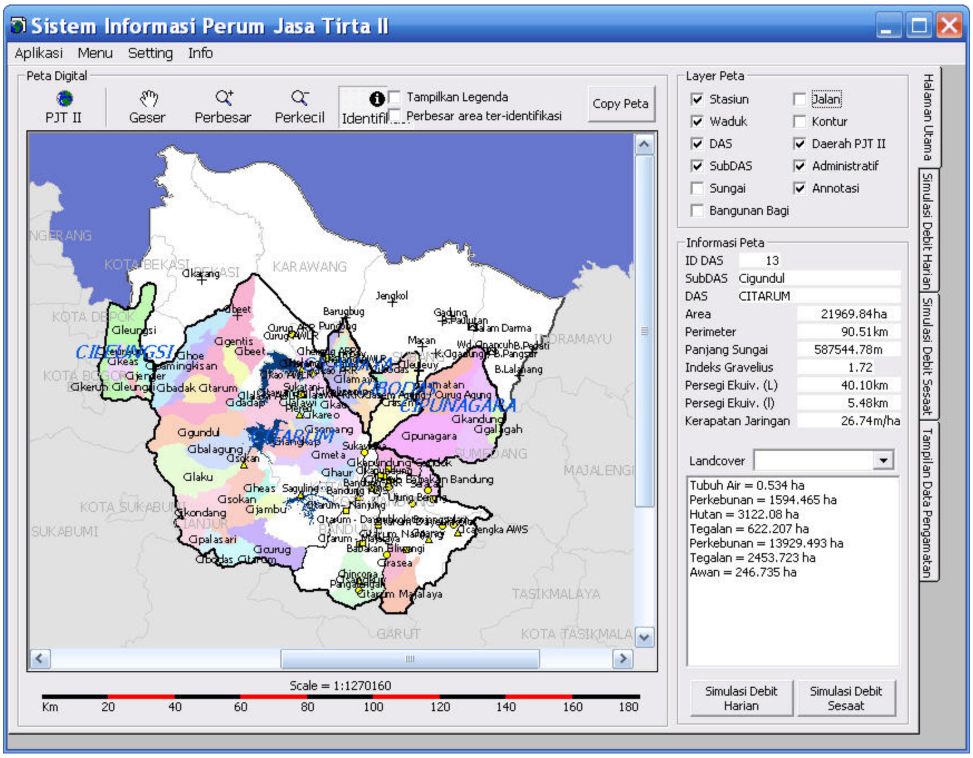

Fig. 2 The opening menu of the Citarum Water Resources Information System.

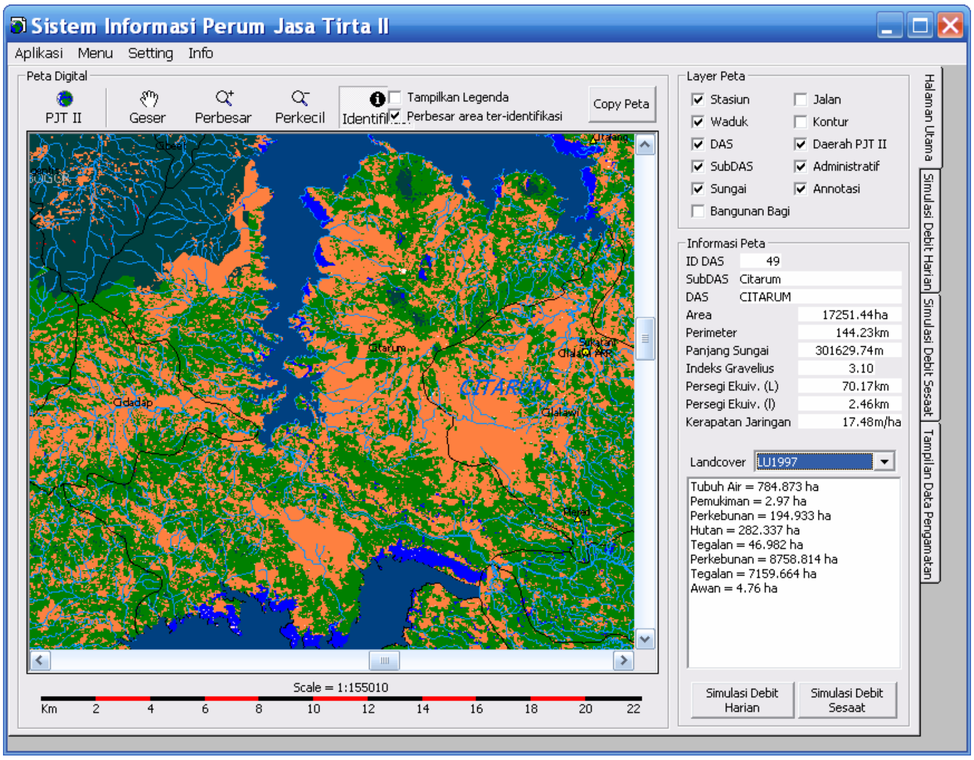

Fig. 3 Kinds of spatial data.

(a)

(b)

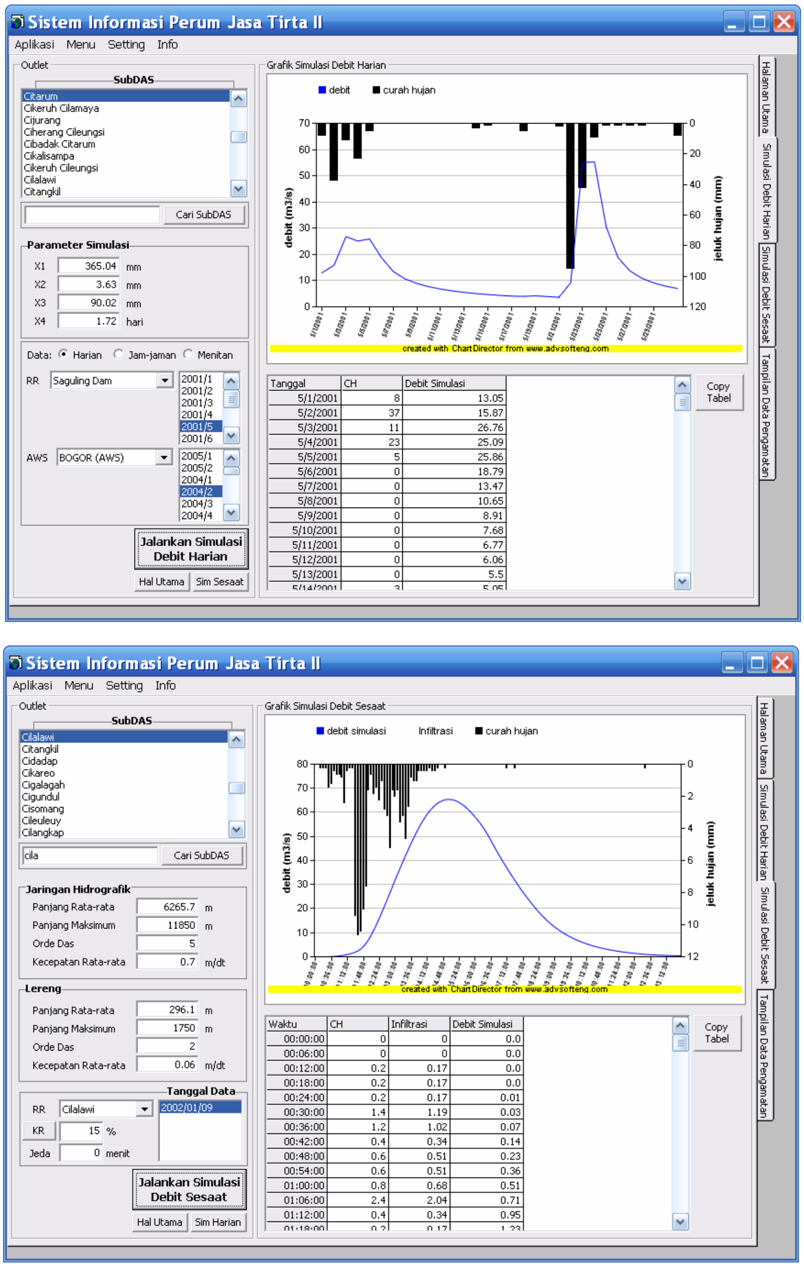

Fig. 4 The capture of (a) the daily discharge and (b) instantaneous discharge by using prediction model that integrated to database system.

Daily simulated discharge menu is developed based on GR4J model application. This menu facilitates the discharge simulation for a watershed/sub watershed based on rainfall and evapotranspiration data as well the parameter model that recorded in database system. The minimum requirement data were watershed information, area, production function method (runoff coeficient or infiltration index/ Φ index) with tranfer function parameter which consists of hydrolic length, velocity of flow, number of order of each drainage network and hillslope. Nash dan Sutcliffe (1970) in Estiningtyas et al. (2005) noted that the correlation coeficient between observed and simulation result using this model was around 0.80.

Instantaneous simulated discharge menu is developed based on the modified H2U model (Kartiwa et al. 2005). The original version of the H2U model ignored the hillslope component. This assumption does not give any problem on a grand watershed application because mean hydraulic length in the hillslope is very short than mean hydraulic length in the channel network so the hillslope effect is not significant. In the modified H2U model, we proposed the modeling of the basin pdf of the travel time through the convolution between the pdf channel network and the pdf hillslope. The model was determined by topographical and drainage network map analysis as well as the calculation module available in instantaneous simulated discharge menu. The requirement data to calcultae the debit were maximum capacity of the production store, water exchange coefficient, maximum capacity of the routing store, and time base of unit hydrograf. Estiningtyas et al. (2005) noted that the correlation coeficient between observed and simulation result using this model was around 0.73.

Recently, PJT II needs information about the water availability in the future, therefore, water status estimation is imperative. Analog with the rainfall we could calculate the water level of the dam for one month, three or six months later. In this case, the water high level bacame as resultant of water balance of the dam, there were rainfall and inlet discharge estimated using H2U or GR4J models as the input and outlet discharge, evaporation, infiltration, and seepage as the output.

In order to disseminate this product to the end user, the user interface has been developed based on LAN and WEB technologies. The LAN interface was developed for internal purposes. The staf could access the whole data as well update the data by using entry data facilities. The WEB interface WEB could accessed by outsider who wants obtain water resources information from PJT II.

CHARACTEISTICS OF THE JAVA MAJOR RIVER BASINS

The hydrology of Java major rivers can be recognized from the seasonal river discharge data that strongly influenced by the biophysical characteristics of the river basins. Seven major river basins representing 35% of the area of Java island were selected that spread from west to east, so that can be considered as representative of the island hydrologic condition. Portions of the developed parts of the basins, as indicated by agricultural, paddy fields and urban areas, already dominated the island with more than 50% as indicated on Table 2.

It is interesting to note that paddy field areas for Citarum and Cimanuk already passed over 30% of basin area, while the others are already between 20 to 24%, while it is understood that 20% is considered as a threshold of carrying capacity for paddy sawah. Therefore, it is understandable that the hydrologic conditions of Java Island have been in critical state for some time now. Another point to make is the proportion of urban areas, especially for Bengawan Solo basin that already passed 30%, while for forest covers all basins consistently have less than 30% as mandated in the Forestry Law (1999) as well as of National Spatial Plan Law (2007). Natural forest cover has been decreasing in the last century from 90% in late 1800s, to only about 4% in 2005 (Baplan-Dephut RI, 2007), and with plantation forest (including private forest) at about 18%, another critical situation.

Table 2 Biophysical and land use characteristics of river basins.

No.	Names of Rivers	Length [km] Catchment area [km^2]	Highest peak [m] Lowest point [m]	Cities Population (1995, 2000)	Land Use [%] (1977, 2000)
1	Ciujung*	147.5 1934.7	Mt.Halimun 1764 ---	Serang --	A(20); F(40); L(1.0); P(20); U(10); O(9.0)
2	Cisadane	137.6 1 266.6	Mt. Pangrango 3 002 River mouth, 0	Bogor 4 018 000 (2000) Tangerang 1 502 000 (2000)	A(48.52); F(16.34); L(1.15); P(22.77); U(11.22)
3	Citarum	269 6 080	Mt.Wayang 1 700 ---	Bandung 2 513 000	A(18); F(20); L(2.5); P(30); U(29.5)
4	Cimanuk River (Main River)	230 3 600	Mt. Ciremai, 3 078 River mouth, 0	Cirebon 256 134 Indramayu 89 182 Garut 104 319	A (29.76); F (22.76); P(35.99); L (0.01); U (6.55); O(4.93)
5	Citanduy	170 4 460	Mt.Cakrabuana 1 750 0	Tasikmalaya 187 609 Ciamis 145 406 Banjar 130 197	A(48.05); F(9.32); L(0.08); P(23.64); U(16.56); O(2.35)
6	Serayu (Main River)	158.4 3 383	Mt. Prahu 2 565 0	Purwekerto 209 005 Cilacap 212 119	F(17.00); P(24.62); A(35.64); U(22.74)
7	Bengawan Solo	600 16 100	Mt.Lawu 3 265 ---	Solo 525 371 Ngawi 829 726	A(25.3); F(19.5); L(0.9); P(21.9); U(32.4)

Source: Catalog of Rivers. A: Agricultural; F: Forest; L: Lake, river, marsh, P: Paddy field, U: Urban, O: Others, * different source.

Hydrologic characteristics of these major rivers, as presented on Table 3, show strong seasonal variations with ratios of maximum discharge to minimum discharge 20 to well over 100, and it is recognized that these ratios are increasing almost for all rivers in Java. The decreasing trends in flow patterns are characterized by increased maximum discharges and lowered minimum discharges. Therefore, indicate the deterioration of water storage capacity of the basins, naturally on the natural water bodies, as well as on reservoirs and dams.

Nugroho (2006) studied the characteristics of river flows in Java, considering the upstream, middle, and downstream sections, and concluded that significant changes had occurred dominated with decreasing trends in the downstream sections as given on Table 3. These flow patterns are also characterized by amplifying flow regimes, with increasing maximum discharges from intense rainfalls and lower low flows from prolonged droughts. The influenced of ENSO (El Nino Southern Oscillation) and Indian Ocean Dipole Mode were believed (Aldrian, 2006), though decreasing regional rainfall in Java island is very much attributed to the disappearing of Java forest cover

Tabel 3 Summary of trends of river flow patterns according to basin sections.

No.	River Name	Trends of Flow patterns		
		Upstream	Middle	Downstream
1	Ciujung	Very decreasing	decreasing	Decreasing
2	Cisadane	Moderately decreasing	Highly increasing	-
3	Citanduy	Moderately increasing	Increasing	Decreasing
4	Citarum	Normal	-	Decerately decreasing
5	Cimanuk	Very decreasing	Moderately decreasing	Normal
6	Serayu	Decreasing	Moderately decreasing	Decreasing
7	Bengawan Solo	Highly increasing	Moderately decreasing	Moderately decreasing

Source: Analyzed from avail. discharge data, 1973-2003.

in the last century.

Regional characteristics of Java water resources can be shown from values of specific discharge of the rivers, ranging from 15 m3/s/100km2 to 80 m3/s/100km2, but mostly under 30 m3/s/100km2 except for Serayu and Ciujung. It is believed that at present conditions, these specific discharges of Java's rivers are somewhat lower than those historical conditions, as summarized in the study of Nugroho (2006) and shown on Table 4.

CONCLUSION

Hydrometeorological monitoring network of Java Island and characteristics of the major river basins have been reviewed on this paper. There were many developments and improvements in this topics however there are still remaining tasks that we have to carry out such as: improving the distribution of ground based observation, applying the system to other watershed, improving the output of analysis and prediction, coordinating the different water authorities, contribution to JSPS activity is to develop database system for Ciliwung basin and other experimental basins, integrating analysis results to the database, and developing interface of the database to the hydrologic modeling parts for simulation possible changes.

Table 4 Hydrologic characteristics of Java major rivers.

No.	Station	Location	Catchment area (A) [km^2]	Observation period	Observation items[1)] [frequency]	$\bar{Q}$[2)] [m^3/s]	Qmax[3)] [m^3/s]	$\overline{Qmax}$[4)] [m^3/s]	$\overline{Qmin}$[5)] [m^3/s]	$\bar{Q}$/A [m^3/s/100km^2]	Qmax/A [m^3/s/100km^2]	Period of statistics
1	Ciujung-Kragilan	S: 06°08'11.2" E: 106o18'01.0"	1 857	1969-2003	Q(d)	99.7	1200	700	20	5.11	60.0	1969-2003
2	Cisadane-Batubeulah	S 06° 29' 00" E 106° 41' 00"	819.60	1968 - 2000	Q (d)	134.7	438.4	305.6	19.95	4.48	14.59	1970~1997
3	Citarum-Tanjungpura	S: 06° 20’ 00” E:107° 19’ 00”	5 970	1969-1977	Q(d)	171	1250	851	15.74	2.86	20.9	1969-1977
4	Citanduy	S: 07° 24’ 00” E:108° 42’ 00”	2 515	1969-1984	Q(d)	204.0	987	710.6	16.27	8.11	39.24	1969-1984
5	Cimanuk-Rentang	S 06 ° 43’ 00” E 108 ° 10’ 00”	3 003	1970-1997	Q(d)	273.4	2 020	1 497	58.80	10.39	76.78	1971~1995
6	Serayu-Rawalo	S 07°30’34” E 109° 17’ 14”	2 631	1971-1995	Q(d)	95.1	254	111.7	61.041	11.60	30.991	1970- 2001
7	B.Solo-Babat	S: 07° 07’ 12” E:112° 09’ 36”	14 247	1982-1991	Q(d)	404.3	2207	1731	26.2	2.84	15.9	1982-1991

Source: Catalog of Rivers

[1]Q: Discharge; [2)] Mean annual discharge; [3)] Maximum monthly discharge; [4)] Mean maximum monthly discharge; [5)] Mean minimum monthly discharge

d: daily (Source: Cat. Rivers)

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Effects of weathered granitic bedrock on runoff processes in a small headwater catchment

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Abstract Recent studies have suggested large influences of bedrock groundwater on runoff generation, water chemistry, and landslides occurrences in headwater catchments. In order to clarify physical water flow process between soil and shallow bedrock, and its effect on storm and base-flow discharge processes in a small headwater catchment underlain by weathered granite, this study conducted hydrometric observations using soil and bedrock tensiometers combined with numerical simulation analyses. Results showed that, in an unchanneled 0.024-ha headwater catchment, saturated and unsaturated infiltration from soil to bedrock is a main hydrological process at the soil-bedrock interface. Annual bedrock infiltration ranged 35 to 55% of annual precipitation and increased as precipitation increased, suggesting a large potential of bedrock infiltration, which was partly explained by a large buffer capacity of soil layer overlying the bedrock. Physical property of soil layer was an important factor to control generations of bedrock infiltration and saturated lateral flow over the bedrock.

Key words storm runoff, baseflow, forest soil, bedrock, numerical simulation, granite

INTRODUCTION

Recent researches have demonstrated the importance of shallow bedrock flow in headwater catchments with any kinds of geologic characteristics. These studies have indicated great contribution of bedrock groundwater to storm runoff generation [e.g., *Wilson et al.*, 1993] as well as base flow discharge [e.g., *Mulholland*, 1993]. Many studies have pointed out that bedrock groundwater flow plays a significant role in occurrence of landslides [e.g., *Montgomery et al.*, 2002]. Moreover, water flow through bedrock is closely related to solute transport and water chemistry in headwater catchments [e.g., *Katsuyama et al.*, 2004]. Thus, it is essential to clarify hydrological interaction between soil and shallow bedrock and water flow processes in the bedrock for modeling runoff generation and water chemistry, and predicting time and location of landslide initiation.

The objective of this study is to clarify the physical water flow process between soil and shallow bedrock and within the bedrock, and its effect on storm and base-flow discharge processes in a small headwater catchment underlain by weathered granite. For this purpose, hydrometric observations using soil and bedrock tensiometers are combined with numerical simulation analyses. Based on the results, we examine the importance of soil-bedrock interaction on hydrological processes in head water catchment.

METHOD

Study Site

Field observations were conducted at the Kiryu Experimental Watershed (WK; 5.99 ha; Fig. 1a), located in the southern part of Shiga prefecture, central Japan (34º58'N, 136º00'E). The climate is warm temperate, with rainfall distributed year round, peaking in summer, but producing little snowfall in winter. The mean annual precipitation from 1972 to 2002 was 1630.0 mm. The mean annual air temperature from 1997 to 2002 was 13.9ºC. We selected a 0.086-ha catchment named Akakabe Watershed (WA) within WK for discharge measurements (Figs. 1a and 1b), and an unchanneled 0.024-ha headwater catchment (WS) in WA for an intensive monitoring (Fig. 1b).

WK is covered with a closed forest mainly consisting of Japanese cypress (*Chamaecyparis obtusa*) and oak (*Quercus serrata*). Whole WK is underlain by granitic bedrock called Tanakami Granite. WA is predominantly covered with Japanese cypress planted in 1959. A stonemasonry dam exists in the catchment, which was constructed about 75 to 95 yeas ago for preventing sediment discharge (Fig. 1b). A spring outflow points, existing below the dam, recharges a perennial stream channel. Sediment had deposited in the upslope area from the dam, with a thickness up to 175 cm. A perennial groundwater exists in this sedimentation area. The area upstream from the sedimentation area consists of two unchanneled head water catchments, one of which is WS. Below the outlet of WS, a pit was excavated to observe a profile from soil through the weathered bedrock, and to take soil and rock samples for hydraulic property measurements (Fig. 1b).

Figure 1c shows the longitudinal section along the hollow of WS indicated by the line A–B in Fig. 1b. A penetration test was conducted at 5 points along the hollow, by using a cone-penetrometer with a 60º bit, a cone diameter of 30 mm, a weight of 5 kg, and a fall distance of 50 cm. From the results of the penetration test, we computed N_c value which represents the number of blows required for a 10-cm penetration. Based on investigations in granite mountains, previous studies [e.g., *Okunishi and Iida*, 1978] have found that N_c of 50 can be a rough index for the boundary between soil and bedrock. The penetration test produced a sudden increase in N_c, indicating the depth of soil-bedrock interface (Fig. 1c). The soil thickness was small in crest, large in middle slope part, and very small around the outlet of WS.

Laboratory tests using the soil samples (100 cc in volume) collected at the pit showed that soils 15- and 30-cm deep from soil surface have the saturated hydraulic conductivity of 0.0507 cm/s with a standard deviation of 0.0216 cm/s (n = 4). Water retention curves observed for the soil samples had large changes in the volumetric water content θ in the region where the pore water pressure head, ψ, was greater than about -50 cmH_2O, suggesting large water holding capacities of soils near saturation.

Hydrological Observations

Precipitation was measured using a 0.5-mm tipping bucket rain gauge at the meteorological station located at the center of WK (the open square in Fig. 1a). The discharge rate at the outlets of WK and WA were measured by using weirs with 90- and 30-degree triangular notches, respectively (Figs. 1a and 1b). At the outlet of WS, the soil thickness was less than 20 cm (Fig. 1c), and we dug a trench over the weathered bedrock and installed an impermeable wall 20 cm high and 160 cm wide for collecting discharge from the soil layer (Figs. 1b and 1c). The collected water flows through a PCV pipe to a 200-cc tipping bucket gauge situated in the sedimentation area in WA (Fig. 1b).

Pore water pressures in soil profiles were measured at seven points (T1 through T7 in Fig. 1c) by using tensiometers (DIK-3150, Daiki Rika Kogyo, Tokyo, Japan). At each point, the deepest tensiometer measured the pressure over the weathered bedrock. At T3, T5, and a point between T6 and T7 (T6a in Fig. 1c), tensiometers (DIK-3151, Daiki Rika Kogyo, Tokyo, Japan) were installed in the weathered bedrock. Electric hammer drills (GBH 3-28FE, BOSCH, Yokohama, Japan) equipped with a drill bit (HEX 190 100, Miyanaga, Hyogo, Japan) were used to make holes in the bedrock, since the bedrock was too hard to be drilled with a hand auger penetration. After the tensiometers were inserted in the drill holes, space between the rock and tensiometer pipes was filled with epoxy resin or impermeable cement. Whole of the 32 tensiometers were automatically measured. The recording interval of all meteorological and hydrometric data was 10 minutes.

RESULTS

Hyetograph and Hydrographs

The total precipitation in the discharge observation period (i.e., May 10, 2002 through Dec. 31, 2003) was 2778 mm. In the same period, total discharge from WK and WA were 1352 and 1205 mm, respectively. That is, the total discharge from WA was about 89% of that from WK. During the summer in 2003, we had more precipitation than we did during the summer in 2002 (Fig. 2a), which resulted in the large base flow discharge of both WK and WA (Figs. 2b and 2c, respectively). The base flow discharge of both WK and WA never disappeared even in the dry summer in 2002 nor during the dry winter season. On the other hand, we never observed base flow discharge from WS. Hydrographs of WS were peaky corresponding to the rainfall peaks (Fig. 2d), and the discharge always disappeared within 12 hours after the rainfall stopped.

Figure 3a shows the relationship between total rainfall and total storm discharge from WS for each storm event. In this study, we assumed that storm events are separated by no-rain period of 12 consecutive hours, and defined the end of each storm as the time point 12-hours after the rain stopped. In Fig. 3a, the total storm discharge is equal to the whole discharge from WS, since the discharge always disappeared within 12 hours after the rainfall stopped as mentioned above. The figure indicates that the total discharge was always smaller than about 5% of the total rainfall. This result contrasts to the results in Fig. 3b which shows the relationships between total rainfall and total storm discharge from WK and WA. For these watersheds, the total storm discharge were greater than 5% of total rainfall for many storm events, and increased up to about 30%. It is noted that the storm discharge for WK and WA was assumed as the increment of discharge from the initial discharge, since the both watersheds had consecutive base flow discharge. As a result of Fig. 3, WS had much less storm discharge than WA and WK, suggesting a large water loss in WS caused by infiltration into the weathered bedrock.

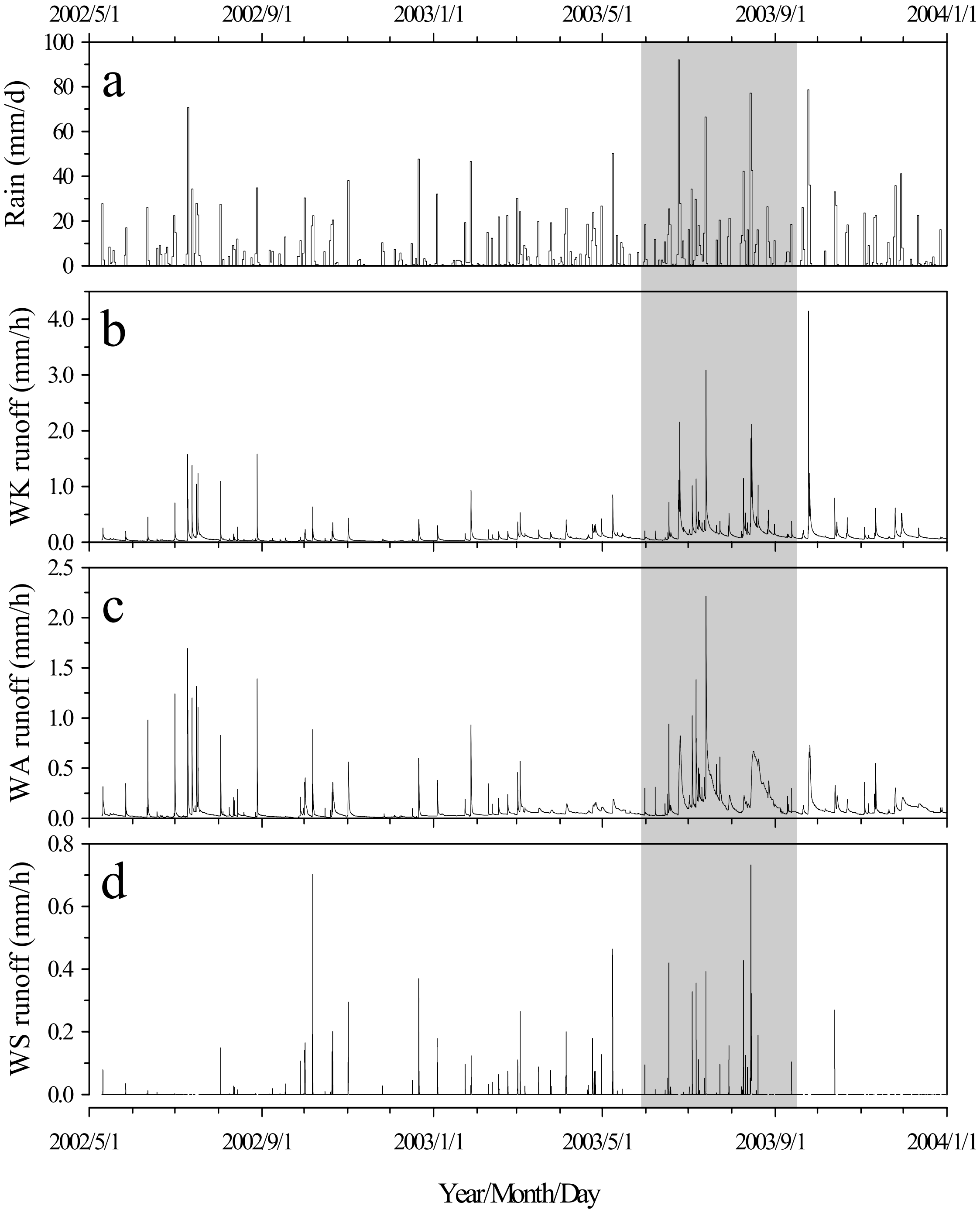

Fig. 2 (a) Hyetograph and hydrographs from (b) WK, (c) WA, and (d) WS. The shaded period corresponds to the tensiometric observation periods shown in Fig. 4.

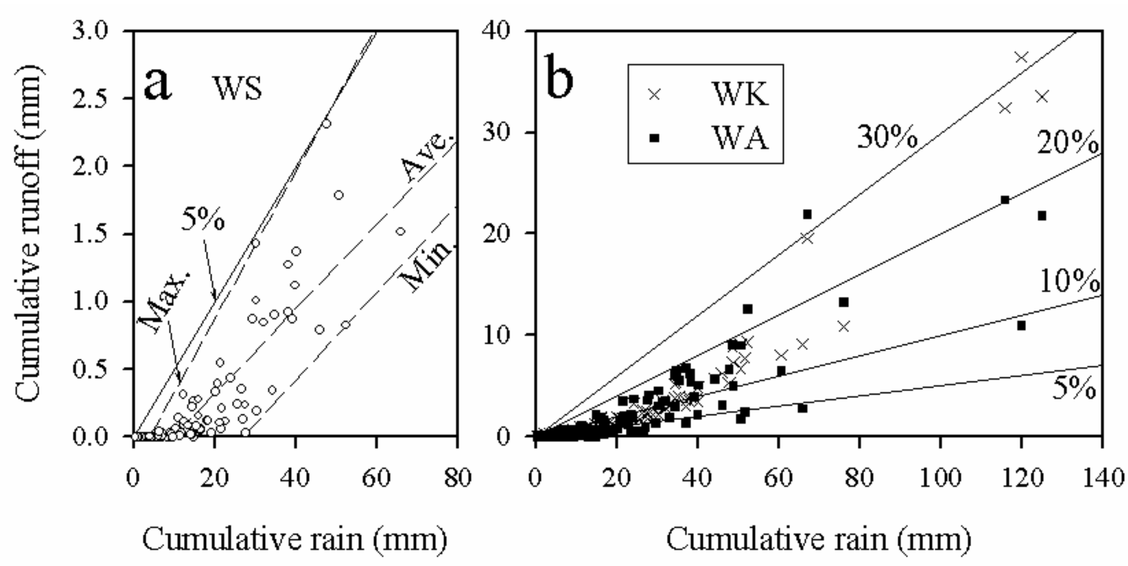

Fig. 3 Relationships between total rainfall and total storm runoff for (a) WS and (b) WK and WA. Solid lines indicates runoff ratios.

Tensiometer Responses

Figure 4c shows rapid and peaky responses of pore water pressures over the weathered bedrock at the points T1 through T3, which can be attributable to the small soil thicknesses at these points (Fig. 1c). The tensiometers frequently observed positive pressures indicating generations of tentative saturation zones. On the other hand, the points T4 through T7 had relatively large soil thicknesses (Fig. 1c), and Fig. 4d shows gentler responses of pore water pressures over the weathered bedrock at these points than those shown in Fig. 4c. Especially at the points T5 and T6, the soil thicknesses were the largest, and the pore water pressures did not took positive values during the whole observation period.

At all depths and all observation points, pore water pressures in the weathered bedrock exhibited substantial changes corresponding to storm events (Figs. 4e through 4g). While some pressures took positive values under heavy storm events, pressures at some points decreased below -200 cm under dry conditions. These results support the finding in Fig. 3 that WS has large water loss by infiltration into the weathered bedrock. Moreover, Figs. 4e through 4g indicate occurrences of both saturated and unsaturated water flow in the weathered bedrock.

At each point of T3, T5, and T6a, the pore water pressures in the shallow bedrock (i.e., 10 to 40 cm deep from the soil-bedrock boundary) generally had similar responses to the pore water pressure over the weathered bedrock (indicated by the gray lines in Figs. 4e through 4g). That is, the time series of pore water pressure in the weathered bedrock is greatly affected by infiltration processes in the overlying soil layer.

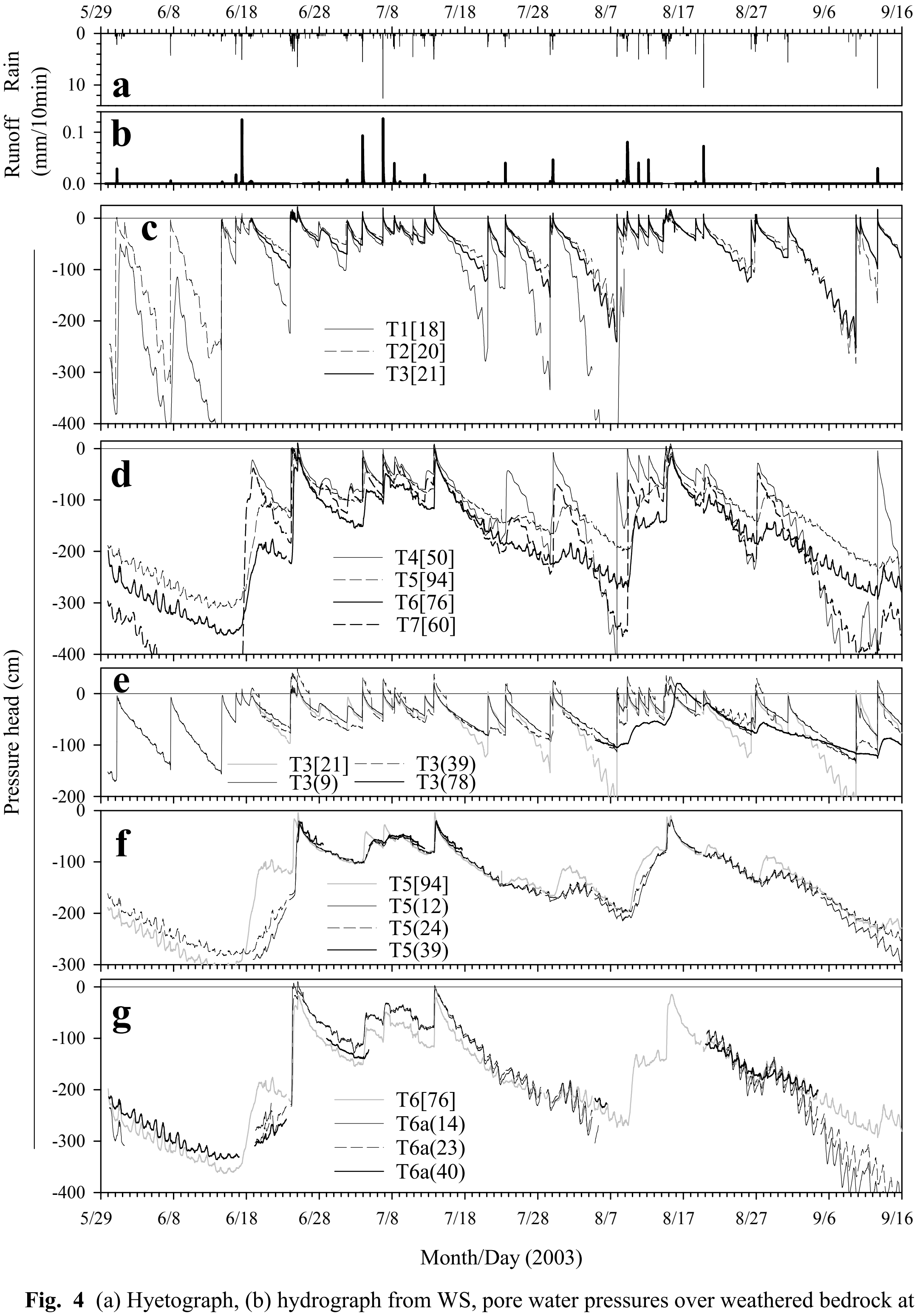

Fig. 4 (a) Hyetograph, (b) hydrograph from WS, pore water pressures over weathered bedrock at points (c) T1 through T3 and (d) T4 through T7, and pore water pressures in weathered bedrock at points (e) T3, (f) T5, and (g) T6a. Points and depths for tensiometer installation are summarized in Fig. 1c. Gray lines in Figs. 4e through 4g represent pore water pressures over the weathered bedrock. In Figs. 4c through 4g, square-bracketed numbers represent depths of soil tensiometers measured from soil surface(in cm). In Figs. 4e through 4g, parenthesized numbers represent depths of bedrock tensiometers measured from soil-bedrock interface (in cm).

NUMERICAL SIMULATION

Method of Simulation

Based on the results of the field hydrological measurements, numerical simulations for saturated and unsaturated water flow were conducted for analyzing rainwater infiltration and discharge processes at a forested hillslope underlain by permeable bedrock. Two-dimensional Richards' equation was solved numerically by using the finite element method assuming triangle elements. The entire calculation domain is shown in Fig. 5. An observed storm hyetograph was supplied to the soil surface. The hyetograph was observed at Nagoya Japan, on 11 to 12 September 2000, having the total precipitation of 566.5 mm. We also examined the case that the observed rainfall intensities were decreased to one-fourth. The soil thickness was fixed at 0, 1, or 2 m. Then, the seepage from bedrock, saturated through flow from soil, and overland flow were computed. The hydraulic properties of the soil and bedrock layers were fixed at the observed characteristics as described in Katsura et al. [2006].

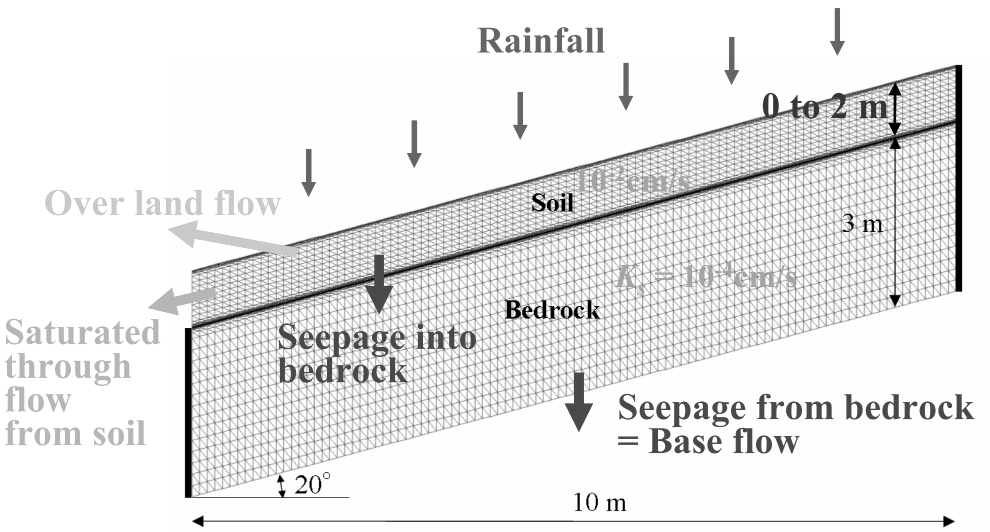

Fig. 5 Slope and triangle elements assumed for numerical simulations (case of 1-m soil thickness).

Results of Numerical Simulation

Figure 6 shows how the spatial distribution of matric pressure changed during the storm event. The figure showed the results when the soil thickness was 1 m and the observed hyetograph was applied. Just after the peak rainfall occurred, the soil layer was unsaturated and had large matric pressure heads (Fig. 6b). Then, 20 minutes after, a saturated zone was formed above the bedrock and the saturated through flow was formed (Fig. 6c). The saturated zone gradually expanded into the bedrock layer (Figs. 6d and 6e).

Figure 7 summarized how the storm water was separated into the overland flow, saturated through flow from soil layer, and seepage from bedrock that was supposed to recharge baseflow. When the rainfall magnification was one-fourth, most of the storm rainfall fed baseflow discharge if a soil layer had a thickness greater than 1 m. Without the soil layer, about 40% of the storm water discharged as the overland flow. When the rainfall magnification coefficient was increased to one, every simulation run produced flood discharge consisting of overland flow and saturated through flow from soil layer. As the soil thickness increased, the flood discharge decreased and baseflow increased. Thus, we conclude that, as the thickness of soil layer increases, the buffer function of the soil layer is enlarged, resulting in increased amount of rainwater infiltration into the permeable bedrock.

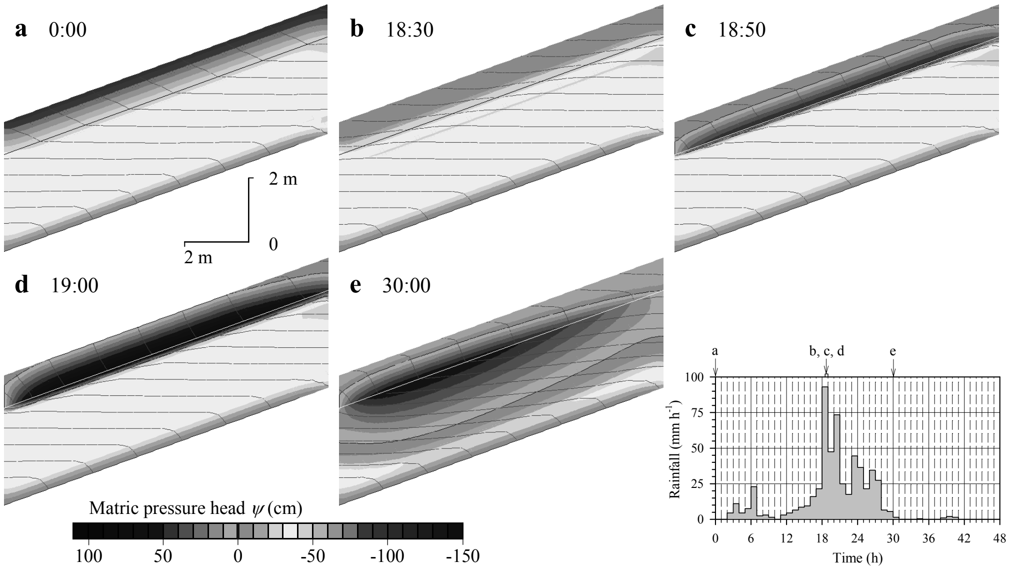

Fig. 6 Simulated matric pressure head for cases of 1-m soil thickness. Black or white line indicates boundary between soil and bedrock. Grey lines are equi-hydraulic head lines with 50-cm intervals.

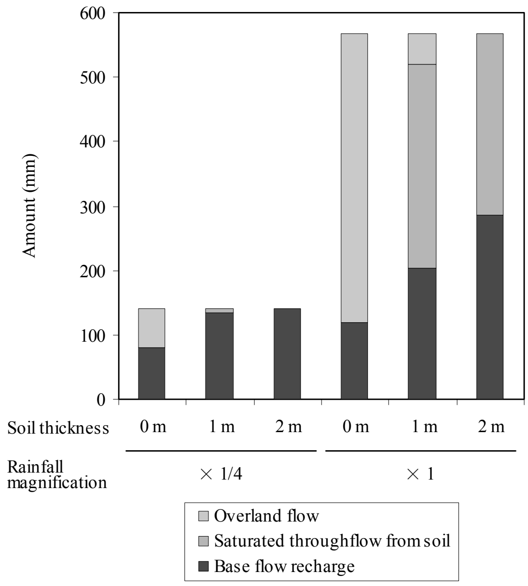

Fig. 7 Separation of input rainfall into overland flow, saturated throughflow from soil, and base flow recharge.

CONCLUSIONS

This study conducted intensive hydrometric observations at watersheds underlain by weathered granite, and numerical simulations on rainwater discharge at a hillslope underlain by a permeable bedrock, revealing the followings:

(1) Base flow discharge both from a watershed of 5.99 ha (WK) and a sub-watershed in WK (WA; 0.086 ha) never disappeared even in dry periods. On the other hand, we never observed base flow discharge from a 0.024-ha headwater catchment (WS) in WA.

(2) The total storm discharge from WS was always smaller than about 5% of the total rainfall, indicating a large water loss in WS caused by infiltration into the weathered bedrock.

(3) Around the outlet of WS, all of rainwater infiltrated into the bedrock by forming unsaturated flows for small storms. Under medium and large storm conditions, the small water-holding capacity of soil layer, which stems from the shallow soil depth, lets the infiltration intensity at the soil-bedrock interface increase, resulting in a formation of saturated zone in the soil layer, causing saturated lateral flow over the bedrock and expansion of the saturated zone into the bedrock, simultaneously. After storms, the saturated zone in bedrock gradually shrinks from the surface, and unsaturated infiltration flux becomes dominant.

(4) In the middle- and up- slope regions in WS, large water-holding capacity of soil layer, which stems from a large soil thickness, results in the large ability as a buffer to reduce infiltration intensity at the soil-bedrock interface. Consequently, whole rainwater infiltrates into the bedrock. Thus, middle- and up- slope regions never become contribution areas for WS discharge, but contribute to the large potential of water loss by bedrock infiltration.

(5) Results of numerical simulation showed that, while an exfiltration from the bedrock sustains base flow discharge, soil layer behaves as a buffer, moderating the infiltration intensity relative to the rainfall intensity and permitting large amount of rainwater to infiltrate into the bedrock.

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Mixing analysis of groundwater recharge sources for better watershed management

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Abstract This paper describes application of three-end member mixing model with isotopic tracers to analyse groundwater recharge sources in the Nasu Fan, Japan. Relative contribution of river water accounts for 50-60% at areas adjacent to interrupted rivers, and precipitation fallen onto the fan is dominant recharge source at the other areas. Contribution ratio of paddy-field water is 30% at most. Implication of such results for better watershed management is given.

Key words tracer, stable isotope, groundwater-surface water interaction, rice paddy field, alluvial fan, end-member mixing model

INTRODUCTION

In an alluvial fan, there exist intensive groundwater-surface water interactions. For instance, rivers are often interrupted at the apex and/or middle zones of the fun because much river-water infiltrates underground and percolates toward water table through highly permeable sand/gravel layer(s). Similarly, precipitation fell onto the ground and irrigated water in paddy fields also easily infiltrate and recharge groundwater. On the other hand, we can find revival of the interrupted river and many springs at the rim zone of the fun, due to effluent seepage of groundwater. Such surface waters provided by groundwater discharge have played a crucial role in maintaining human activities and natural ecosystems. Therefore, assessment and conservation of various sources of groundwater are important issues for better managing of watershed particularly in alluvial fan.

The present study aims to evaluate quantitatively the relative contributions from different sources, such as river water, precipitation and irrigated paddy-field water, by a mixing analysis using stable isotope tracers.

STUDY AREA AND METHODOLOGY

The study area is the Nasu Fan, central Japan (Fig .1), which is a compound fan formed by four rivers (i.e., the Naka, Kuma, Sabi and Houki rivers). The two (the Sabi and Kuma rivers) of the four are fully interrupted at the apex zone and revive at around the boundary between the middle and rim zones. Total area of the fan is approximately 400km, with elevation ranging from 100 to 600 m a.m.s.l. Land use type is dominated by pasture and forest in the apex zone, and rice paddy and vegetable field in the middle

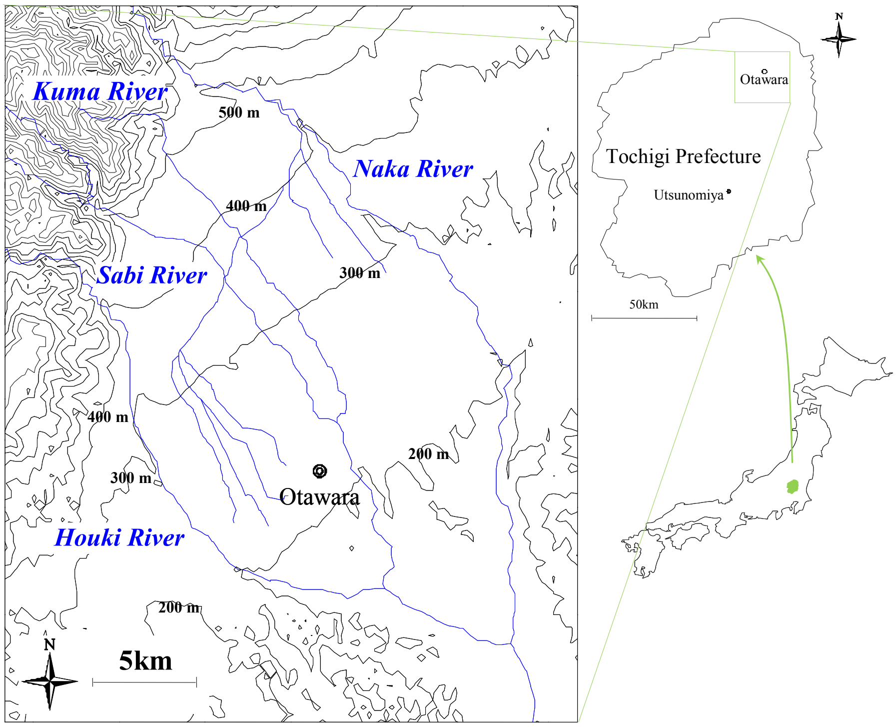

Fig. 1 Location and topography of the study area.

and rim zones.

Water table is situated within sand/gravel layers (called *Nasu Alluvial-fan Gravels* and *Torinome Gravels*) overlain by loamy soil layer with a thickness of approximately 2 m, and underlain by pyroclastic flow sediments (called *Otawara Pumice-flow*), which act as aquitard. The thickness of sand/gravel layers ranges from 20 to 30 m at the middle zone. Annual mean temperature is approximately 12 ºC, and annual precipitation is approximately 1350 mm.

The present study mainly focused on groundwater at the middle zone (with elevation ranging from 250 to 360 m), and ten wells were selected in the zone for groundwater sampling. The groundwater samples were collected every month during one full year from February 2004 to February 2005. In addition to groundwater, samples of river water (at four rivers), precipitation (at one site) and paddy-field water (at five sites) were also collected as potential recharge sources. All the collected samples were analyzed for hydrogen and oxygen stable isotopic compositions (δD and $\delta^{18}O$) by a mass spectrometer (MAT252, Thermo Finnigan). Furthermore, groundwater level and water quality (including temperature, pH, electric conductivity and major ions concentration) were measured.

RESULTS AND DISCUSSION

Annual average δD and $\delta^{18}O$ in precipitation were -56.7‰ and -8.8‰, respectively. The values were lower in river water and higher in paddy-field water. The deuterium excess, *d* ($\equiv \delta D - 8\,\delta^{18}O$), was significantly lower in paddy-field water, indicating kinetic fractionation during evaporation from flooded water surface. In the δ-diagram groundwater isotopic data were plotted within a triangle of which end members are river water, precipitation and paddy-field water. This fact suggests that the groundwater is a mixture of these source waters.

Thus, a three end-member mixing model can be applied. This model is based on conservation of water, hydrogen isotope, and oxygen isotope. Relative contribution ratio, *R* (%), for each source can be obtained by solving simultaneously the three conservation equations, as:

$$R_p = \frac{(\delta D_g - \delta D_d)(\delta^{18}O_r - \delta^{18}O_d) - (\delta^{18}O_g - \delta^{18}O_d)(\delta D_r - \delta D_d)}{(\delta D_p - \delta D_d)(\delta^{18}O_r - \delta^{18}O_d) - (\delta^{18}O_p - \delta^{18}O_d)(\delta D_r - \delta D_d)},$$

$$R_r = \frac{(\delta D_g - \delta D_d)(\delta^{18}O_p - \delta^{18}O_d) - (\delta^{18}O_g - \delta^{18}O_d)(\delta D_p - \delta D_d)}{(\delta D_r - \delta D_d)(\delta^{18}O_p - \delta^{18}O_d) - (\delta^{18}O_r - \delta^{18}O_d)(\delta D_p - \delta D_d)},$$

$$R_d = 1 - R_p - R_r,$$

where subscripits p, r, d and g denote precipitation, river water, paddy-field water and groundwater, respectively.

Figure 2 shows spatial distribution of the computed *R* values. At an area adjacent to interrupted rivers (i.e., the Sabi and Kuma rivers), contribution ratio of river water is generally high. In contrast, at areas apart from rivers, river water shows no contribution and most of groundwater are recharged by precipitation onto the fan. While contribution of paddy-field water can be also found at all the region, the *R* is 30% at most. The results also indicate that the Houki River recharges groundwater, whereas the Naka River does not. The reason why there is no recharge from the Naka River is because river bed is situated far lower than water table within the fan. Validity of these findings from the mixing analysis is supported qualitatively by hydraulic data and the other data of water quality.

Knowledge of relative contribution of different groundwater sources allows us to discuss the effect of water use or land use on groundwater resources. In areas where river water contribution is dominant, construction of dams or river water pollution upstream will cause severe damage to quantity and quality of groundwater body. In areas where precipitation contribution is dominant, live stock farms and fertilization in pasture land or vegetable field may result in nitrogen contamination of groundwater. Construction of industrial waste landfills would also affect groundwater quality. In areas where paddy-field water contribution is dominant, abandonment of rice cultivation may decrease groundwater recharge and thus lower water table. In the last two areas, groundwater is particularly sensitive to land use change within the fan, so that regional planning including urbanization and agricultural land modifications should be carefully made.

CONCLUDING REMARKS

As shown in the present paper, mixing analysis of groundwater is capable of providing us invaluable information for decision making to manage better water and watershed.

Further studies under diverse geographical conditions are necessary to confirm reliability of the estimates from this approach.

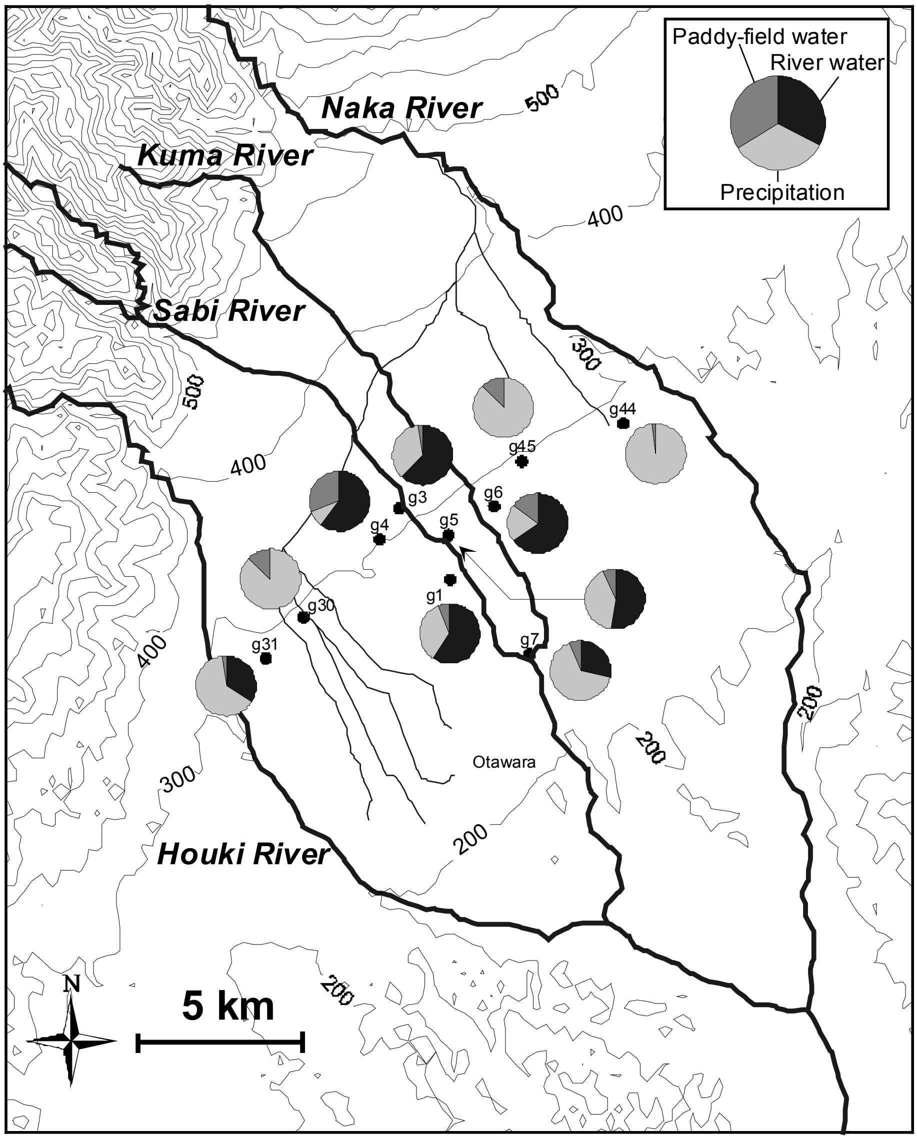

Fig. 2 Spatial distribution of contribution ratio for three possible sources.