Geospatial Technology for Water Resource Applications

Editors

Prashant K. Srivastava
Hydrological Sciences (Code 617)
NASA GSFC
Greenbelt, Maryland
USA
and
Institute of Environment & Sustainable Development
Banaras Hindu University (BHU)
Varanasi
UP
India

Prem Chandra Pandey
Department of Geography
University of Leicester
University Road
Leicester
UK

Pavan Kumar
Department of Remote Sensing, Bhu Mandir
Banasthali University
Tonk, Rajasthan
India

Akhilesh Singh Raghubanshi
Institute of Environment & Sustainable Development
Banaras Hindu University (BHU)
Varanasi
UP
India

Dawei Han
Dept. of Civil Engineering
University of Bristol
Bristol
UK

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Preface

Information on our planet's water resources is essential for both human society and ecosystems. The world population is increasing at a rapid pace and the demand for water will continue to rise in future. However, the water resources are limited and therefore there is a growing need to monitor this resource and accumulate information in the technical literature domain that could assist the stakeholders towards development of effective water management strategies and infrastructures timely.

In recent decades geospatial techniques have gained considerable interest among the earth and hydrological science communities for solving and understanding various complex problems and approaches towards water resource development. This book is motivated by the desire to solve the problem of increasing scarcity of water resources in a cost effective and timely way. After the development of sophisticated geospatial technology and the launch of several Earth Observation (EO) satellites, it is now possible to monitor water resources regularly, accurately and in real time.

Overtime, geospatial techniques for water resources are becoming increasingly important in a much wider range of scientific and engineering disciplines. Looking at the importance of the subject, many departments across the world have revised their curricula and now have geo-informatics as a core subject along with the others like water resources or hydrology. Most introductory courses on geo-informatics are focused mostly on theory, so we have covered the practical applications of the geospatial techniques in this book, laid on a sound background of hydrology, and geospatial and computational intelligence techniques. Therefore, the main aim of this book is to provide an understanding of GIS, remote sensing and hybrid approaches to students and researchers in order to provide a solid foundation for further studies. The second goal is to provide readers with an insight into advanced courses such as geo-informatics and the conceptual tools that can be used in this field. Finally, a more pervasive goal of the book is to expose all students not only to advanced geospatial concepts but also to the intellectually rich foundations of the field.

After reading the literatures, we have found that it is useful to have a coherent architecture to motivate readers on how geospatial system works but have also found that almost all sets of courses revolve around separate architecture, which is not useful for providing a holistic framework and integration of the aspects. Foundations of geo-informatics cover subjects that are often split between sophisticated mathematical backgrounds and actual applications. Synergy is required between the two to select the mathematical foundations with an eye toward the demand of the users.

In order to simplify geospatial technology for most of the students and researchers, this book focuses on three working methodologies *viz* theory, abstraction and design as they are fundamental to all research programs. This book identifies the key recurring concepts which are fundamental to geospatial technology for water resources, especially: conceptual and formal models, efficiency and levels of abstraction. Following the working methodologies, processes and concepts, the primary aim of this book is to advance the scientific understanding, development and application of geospatial technologies to address a variety of issues related to water resource development. By linking geospatial techniques with new satellite missions for earth and environmental science oriented problems, this book will promote the synergistic and multidisciplinary activities among scientists and users working in the field of hydrological sciences. Many key topics are covered in the book from utilization of GIS, satellite based information to hybrid and artificial intelligence techniques for water resources.

This book has put together a collection of the recent developments and rigorous applications of the geospatial techniques for water resources. It will serve as the first handbook encompassing a spectrum of interests in water resources on a geospatial platform. We believe that the book will be read by the people with a common interest in geospatial techniques, remote sensing, sustainable water resource development, applications and other diverse backgrounds within earth and environmental and hydrological sciences field. This book would be beneficial for academicians, scientists, environmentalists, meteorologists, environmental consultants and computing experts working in the area of water resources.

This book is the result of extensive and valuable contributions from interdisciplinary experts from all over the world in the field of remote sensing, geospatial technologies, coastal science, ecology, environmental science, natural resources management, geography and hydrology representing academic, governmental and business sectors. The Editors are grateful to all the contributing authors and reviewers for their time, talent and energies.

About the Cover

Sophisticated Soil Moisture and Ocean Salinity satellite (Photograph provided by European Space Agency) is shown on the cover providing the state of the art soil moisture information from space. Other photos on the cover show the geospatial information contained by various layers and the land cover for water resources applications.

Maryland, USA — *Prashant K. Srivastava*
Leicester, UK — *Prem Chandra Pandey*
Rajasthan, India — *Pavan Kumar*
Varanasi, India — *Akhilesh Singh Raghubanshi*
Bristol, UK — *Dawei Han*

Contents

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List of Contributors

Muhammad Zulkarnain Abd Rahman

TropicalMap, Faculty of Geoinformation & Real Estate, Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia

Muhammad Ali

Department of Civil Engineering, University of Engineering and Technology, Taxila-47050, Pakistan

Putu Aryastana

Civil Engineering Department, Warmadewa University, Jl Terompong No 24 Tanjung Bungkak, Denpasar, Indonesia

Muhammad Saadoon Basraa

Department of Civil Engineering, University of Engineering and Technology, Taxila-47050, Pakistan

Madan Raj Bhatta

Water Resources Management Program (WARM-P)/HELVETAS, Swiss Intercooperation Nepal, Dhobi Ghat, Lalitpur GPO Box 688, Surkhet, Nepal

Ngai-Weng Chan

School of Humanities, Universiti Sains Malaysia, 11800 USM Penang, Malaysia

Qiang Dai

Key Laboratory of VGE of Ministry of Education, Nanjing Normal University, Nanjing-210046, China

Sandeep Kumar Gautam

School of Environmental Sciences, Jawaharlal Nehru University, New Delhi–110067, India

Dileep Kumar Gupta

Department of Physics, Indian Institute of Technology (B.H.U.), Varanasi-221005, India

Manika Gupta

Hydrological Sciences, NASA Goddard Space Flight Center, Greenbelt-20771, Maryland, USA

Dawei Han

Water and Environmental Management Research Centre, Department of Civil Engineering, University of Bristol, Bristol BS8 1TR, UK

Ab Latif Ibrahim

Geoscience and Digital Earth Centre, Research Institute of Sustainability and Environment, Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia

Moslem Imani

Department of Geomatics, National Cheng Kung University, No. 1, University Road, Tainan City, 701, Taiwan

Tanvir Islam

NASA Jet Propulsion Laboratory, Pasadena, CA-91109, USA; and California Institute of Technology, Pasadena, CA-91125, USA

Swati Katiyar

Department of Remote Sensing, Banasthali University, Newai, Tonk-304022, Rajasthan, India

Anand N. Khobragade

Resource Scientist, Maharashtra Remote Sensing Applications Center, Nagpur-440010, India

Pavan Kumar

Department of Remote Sensing, Bhu Mandir, Banasthali University, Newai, Tonk, Rajasthan 304022, India

Rajesh Kumar

Centre for the Study of Regional Development, School of Social Sciences, Jawaharlal Nehru University, New Delhi-110067, India

S. Prasanna Kumar

Department of Physical Oceanography, National Institute of Oceanography, Dona Paula, North Goa 403004, India

Sanjay Kumar

Rural Development Officer, Govt. of Bihar, Patna-800015, Bihar, India

Chung-Yen Kuo

Department of Geomatics, National Cheng Kung University, No. 1, University Road, Tainan City, 701, Taiwan

Jia Liu

State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, 971#, Building A, No.1-A Fuxing Road, Beijing 100038, China

Panagiota Louka

Department of Natural Resources Development and Agricultural Engineering, Agricultural University of Athens, Iera Odos 75, Athina 11855, Greece

Vinay Mandal

Research Associate, PDFSR Modipuram, Meerut, 250110, Uttar Pradesh, India

Fusanori Miura

Graduate School of Environmental Science and Engineering, Yamaguchi University, Tokiwadai 2-16-1, Ube, Yamaguchi, Japan

Abdul Moiz

Department of Civil Engineering, University of Engineering and Technology, Taxila-47050, Pakistan

Usman Ali Naeem

Department of Civil Engineering, University of Engineering and Technology, Taxila-47050, Pakistan

Boini Narsimlu

Division of FM and PHT, ICAR–Indian Grassland and Fodder Research Institute, Jhansi-284003 (U.P.), India

M.S. Nathawat

School of Life Sciences, Indira Gandhi National Open University, New Delhi-110030, India

Mahesh Neupane

Department of Water Supply and Sewerage (DWSS), Government of Nepal, Kathmandu-32900, Nepal

Prem Chandra Pandey

Centre for Landscape and Climate Research, Department of Geography, University of Leicester, Leicester LE1 7RH, UK

Ioannis Papanikolaou

Department of Natural Resources Development and Agricultural Engineering, Agricultural University of Athens, Iera Odos 75, Athina 11855, Greece

George P. Petropoulos

Department of Geography & Earth Sciences, University of Aberystwyth, Aberystwyth SY23 3FL, Wales, UK

Rajendra Prasad

Department of Physics, Indian Institute of Technology (B.H.U.), Varanasi-221005, India

Akhilesh Singh Raghubanshi

Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi 221005, UP, India

Ragindra Man Rajbhandari

NEST Pvt. Ltd., Shankhamul, Kathmandu-44600, Nepal

Indal K. Ramteke

Scientific Associate, Maharashtra Remote Sensing Applications Center, Nagpur-440010, India

Preeti Rani

Department of Physical Oceanography, National Institute of Oceanography, Dona Paula, North Goa 403004, India

N. Ravishankar

PDFSR, Modipuram, Meerut, 250110, Uttar Pradesh, India

Miguel A. Rico-Ramirez

Water and Environmental Management Research Centre, Department of Civil Engineering, University of Bristol, Bristol-BS8 1TR, UK

A. Besse Rimba

Graduate School of Environmental Science and Engineering, Yamaguchi University, Tokiwadai 2-16-1, Ube, Yamaguchi, Japan

Martiwi Diah Setiawati

Graduate School of Science and Engineering, Department of Environmental Science and Engineering, Yamaguchi University, 2-16-1 Tokiwadai, Ube, 755-8611, Japan

Muhammad Ali Shamim

Department of Civil Engineering, Bursa Orhangazi University, Bursa-16310, Turkey

Rubika Shrestha

Water Resources Management Program (WARM-P)/HELVETAS, Swiss Intercooperation Nepal, Dhobi Ghat, Lalitpur GPO Box 688, Surkhet, Nepal

Abhay K. Singh

Central Institute of Mining and Fuel Research, Barwa Road, Dhanbad, Jharkhand-826001, India

Prafull Singh

Amity Institute of Geo-Informatics and Remote Sensing, Amity University-Sector 125, Noida-201303, India

Sudhir Kumar Singh

K. Banerjee Centre of Atmospheric and Ocean Studies, IIDS, Nehru Science Centre, University of Allahabad, Allahabad-211002 (U.P.), India

Prashant K. Srivastava

Hydrological Sciences (Code 617), NASA GSFC/JPL, Room No. G208, Building 33, Greenbelt, Maryland 20771, USA; Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi 221005, UP, India; and Earth System Science Interdisciplinary Center, University of Maryland, College Park-20742, Maryland, USA

Nikolaos Stathopoulos

Section of Geological Sciences, School of Mining Engineering, National Technical University of Athens, Athens-10682, Greece

Tze-Huey Tam

Geoscience and Digital Earth Centre, Research Institute of Sustainability and Environment, Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia

Jay Krishna Thakur

Environment and Information Technology Centre – UIZ, Neue Grünstrasse 38, 10179, Berlin, Germany

Bikram Rana Tharu

Building Effective Water Governance in Asian Highlands (HELVETAS Swiss Intercooperation Nepal), Dhobi Ghat, Lalitpur GPO Box 688, Kathmandu, Nepal

Vandana Tomar

Haryana Institute of Public Administration (HIPA), 76, HIPA Complex, Sector-18, Gurgaon, Delhi-122001, India

Jayant K. Tripathi

School of Environmental Sciences, Jawaharlal Nehru University, New Delhi–110067, India

Wan Zurina Wan Jaafar

Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

Iain Woodhouse

School of Geosciences, The University of Edinburgh, Edinburgh EH9 8XP, UK

Aradhana Yaduvanshi

Center of Excellence in Climatology, Birla Institute of Technology, Mesra-835215, Ranchi, India

Rey-Jer You

Department of Geomatics, National Cheng Kung University, No. 1, University Road, Tainan City, 701, Taiwan

Section I

General

1

Chapter

Introduction to Geospatial Technology for Water Resources

Prem Chandra Pandey,[1] *Prashant K. Srivastava*,[2,3,4,*] *Pavan Kumar*,[5] *Akhilesh Singh Raghubanshi*[4] and *Dawei Han*[6]

ABSTRACT

Increasing demands on water resources to fulfill the growing population needs have led to a great pressure on the water resources. Water resources conservation and management needs exemplary information regarding the water bodies with respect to quality, quantity and the related driving factors responsible for deterioration and depletion of water. Traditional methods existing in literature are limited to the point locations and manually gathered input dataset for analysis of the water system. However, after the development of advance geospatial technologies, now it is possible to build the digital information that can support analysis and interpretation for a large area in short span of time. The chapter introduces the various geospatial technologies, which are playing a vital and inevitable role in the acquisition of information and development of research capabilities towards water resources. These technologies are required for determining a strategic plan for execution of desired results as applicable to different regions and objectives (for e.g. determination of water-river boundaries, water quality and quantity, soil moisture, flood plains, ocean temperature etc). This chapter provides different methods/applications to demonstrate the importance of traditional and advanced concepts of geospatial technology in water resources. Thus, overall goal

[1] Centre for Landscape and Climate Research, Department of Geography, University of Leicester, Leicester, UK.
[2] Hydrological Sciences, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[3] Earth System Science Interdisciplinary Center, University of Maryland, Maryland, USA.
[4] Institute of Environmental and Sustainable Development, Banaras Hindu University, Varanasi, India.
[5] Department of Remote Sensing, Banasthali University, Newai, Tonk, Rajasthan, India.
[6] Water and Environmental Management Research Centre, Department of Civil Engineering, University of Bristol, Bristol, UK.
* Corresponding author: prashant.just@gmail.com

of this chapter is to provide a summary of different research work carried out in various fields of water resources with demonstrated results and findings that could be able to use in decision making, developing policy and planning at root level. This chapter also provides future challenges in water resources and geospatial technology.

Keywords: Water Resources, Geospatial Technology, Traditional methods, Advance methods, Hybrid Technology, Challenges.

❍ INTRODUCTION

Water is an essential component of natural resources available in many forms such as groundwater, river, springs, lakes, glaciers etc. The importance of water comes from its ability to keep us alive, carry nutrients to crops and plants, dilute wastes and toxic-pollutants and maintain the hydrological cycle. Therefore, water resources management is a significant issue for us today in order to reduce water scarcity for future generations. Nowadays, because of substantial demographic and economic changes there are high fluctuations in the hydrological regime that cause depletion or contamination of water resources. As a result, this precious resource is under pressure and needs conservation management as well as protection.

The vital issue of understanding water resources through geo-informatics is addressed in this book through traditional, advanced, hybrid and artificial intelligence techniques. Water resources management is mainly used to understand and monitor water resources, while geospatial techniques use RS, GIS and GPS applications to facilitate this practice in a timely fashion. Therefore, the aim of this book is to present several ideas towards monitoring of water resources. Apart from its role as a life supporter, water also causes harmful hazards in the form of flood and drought. This book contains several techniques for monitoring and protection of water resources to hazard assessment such as frost, floods and droughts. It also outlines future challenges that need attention for us to cope up with the management of this precious natural resource.

This book is divided into four sections to cover the water resources applications using Remote Sensing, GIS, Hybrid and Artificial intelligence techniques and also provide challenges which need to be addressed in the near future. Section Two provides the geographical information based application on water resources such as flood risk, nutrients for irrigation of agricultural crops, hydropower and watershed management. Chapter 2 provides the master plan for the integrated water resources management using geographical information system. The principle concept of 3R i.e. recharge, retention and reuse are presented in this chapter. This 3R concept with integrated GIS analysis can be used in calculating the current and future hardships for water in catchments. This idea helps in identifying the potential opportunities for critical watershed and hardship zones and implement watershed conservation activities for balancing ecosystem services for water and land use.

Chapter 3 elucidates the spatial integration of soil and water nutrients which are essential for crop growth and production. This chapter presents the sodium absorption ratio (SAR) with different nutrients including nitrogen, phosphorus and potassium for agricultural applications. The different water parameters (pH, organic carbon etc) are used in the spatial mapping of the spatial discrepancies of rice crop based on cropping systems productivity. Finally, this chapter provides the relational pattern in rice equivalent field and nitrate mapping. Chapter 4 focuses on assessment of hydropower potential using Shuttle Radar Topography Mission (SRTM) based Digital Elevation Model (DEM) along with observed discharge. Several locations of river hydropower plants are identified to obtain the results in GIS environment. Results from this study could be helpful in making precise decisions in favour of a sustainable hydropower development and finally alleviate the energy crisis being faced today by the Pakistan. The study also indicates the usefulness of using GIS in carrying out spatial interpolation and consequently, determination of hydropower potential. This chapter apprehends the energy demand due to an increasing population, which is putting a high pressure on the economic growth and proved the importance of renewable energy sources as a prerequisite for sustainable economic growth.

Chapter 5 introduces the flood risk assessment using different techniques and also provides the delineation and zonation of flood risk areas through geo-hydrological parameters. They generate flood risk maps using satellite LiDAR, hydrological data and two dimensional hydraulic models. The authors have presented different techniques to estimate the flood in the residential areas. This chapter has effectively produced the flood risk maps and suggested ideas to improve them by taking into account the epistemic uncertainties. The risk and hazard maps generated in this study will help in reducing socio-economic losses. In Chapter 6, authors have used multi-temporal multi-source images along with secondary data sets such as the inundated and flood atlas to identify flood prone areas. They have delineated three flood zones using the overlay of flood layers of different magnitude and geomorphic features in the GIS environment. Authors have also attempted the categorization of areas into alluvial islands and mid-channel bars, protected embankment, older floodplain with meander scars and scroll bars. The authors have shown the increasing nature of hamlet density in relation to future flood events in the lower Ghaghara river valley. Chapter 7 provides the geospatial approach for water resource management in a watershed using the merged ortho-product of LISS-IV and Cartosat-1D satellites. The authors build water resource development plans by considering the various criteria themes such as slope, soil and land use/land cover. The aim of the chapter is to provide a better use of natural resources by conserving both soil and water resources. The chapter basically deals with the developmental activities to provide soil and water conservation measures by reducing scarcity, erosions, agricultural development as well as to improve ground water.

The third section of the book mainly deals with the satellite based applications in water resources, where flood vulnerable areas, frost risk, precipitation monitoring for flood assessment, surface and ground water for irrigation purposes and sea surface water height anomaly are presented. In this section, Chapter 8 deals with the flood vulnerability prediction using satellite and Amedas data derived products in Japan. The case studies presented in this chapter include the Shiragawa watershed, Japan to predict the flood vulnerable regions. The isohyet map prepared using rain-gauge data is interpolated with kriging applications. Finally, all spatial data are overlaid to create the flood-vulnerability map by application of the GIS model. Chapter 9 deals with the estimation of precipitation for flood monitoring and its validation using the hourly GSMaP (Global Satellite Mapping Precipitation) satellite datasets with MVK (Moving Vector with Kalman Filter), NRT (Near Real Time) data and 27 rain gauges ground based reference station datasets (AMEDAS -Automated Meteorological Data Acquisition System). The study is carried out at spatial resolution 0.1° latitude × 0.1° longitude in Kumamoto Japan, often prone to flash flood, for the temporal duration of 2003 to 2012. The main theme of the chapter is to define the rainfall pattern causing flash flood using statistical analysis. Chapter 10 presents an interesting topic related to qualitative assessment of surface and ground water evaluation using remote sensing, irrigation indices and statistical techniques. The chapter revolves around the main theme of irrigation and drinking suitability of surface and groundwater. To meet the objective, average concentration of several water parameters is determined in the surface and the groundwater samples and presented using geospatial techniques. Chapter 11 discusses the techniques for assessment of spatial and temporal variation of sea surface height anomaly and its relationship with satellite derived chlorophyll-a pigment concentration. The authors derived the sea surface height anomaly (SSHA) data using satellite altimetry and chlorophyll-a concentration from ocean colour, which are subjected to Empirical Orthogonal Function (EOF) analysis to understand the spatio-temporal variability of these parameters in the context of mesoscale eddies. They suggest EOF as an efficient method of delineating a spatial and temporal signal from a long time series data over a large spatial domain. Chapter 12 emphasizes soil moisture deficit monitoring using the Soil Moisture and Ocean Salinity (SMOS) Satellite through rainfall-runoff model. Several approaches for estimation of soil moisture deficit are performed using SMOS satellite soil moisture through Generalized Linear Model with different families/link functions such as Gaussian/logit, Binomial/identity, Gamma/inverse and Poisson/log. The overall performances obtained from all the techniques indicate that the SMOS is promising for simulation of soil moisture deficit.

Section Four focuses on the artificial intelligence and hybrid models for water resource for flood regionalization, soil moisture monitoring, sea level prediction and spatio-temporal uncertainty model for rainfall predictions. Chapter 13 reveals the techniques to measure frost risk and suggests techniques to avoid frost risk in agriculture using MODIS data. The authors present the spatio-temporal distribution of frost conditions in Mediterranean environments. They present a model based on the main factors that include environmental factors such as land surface temperature and geomorphology governing the frost risk. Several topographical parameters such as altitude, slope, steepness, aspect, topographic curvature and extent of the area influenced by water bodies are required in the model to assess the frost risk. MODIS and ASTER polar orbiting sensors, supported also by ancillary ground observation data along with land use and vegetation classification (i.e. types and density) are the required input for the successful determining of the frost risk for the winter period of the four different selected years. Overall, the proposed methodology proves to be capable of detecting frost risk in Mediterranean environments in a time efficient and cost effective way, making it a potentially very useful tool for agricultural management and planning. The proposed model may be used as an important tool for frost mapping, a natural hazard that leads to severe vegetation damage and agricultural losses. Chapter 14 provides a statistical approach for catchment calibration data in flood regionalization. The chapter concluded that the quantity and quality of calibration data are two different entities that could greatly influence the developed hydrological model. The study has demonstrated that the standard deviation values between the best and poorest groups are distinctive and could be used in choosing appropriate calibration catchments. Chapter 15 predicts the Caspian Sea level fluctuations using artificial intelligence and satellite altimetry. This chapter presents different approaches for studying the sea level anomaly, fluctuation and analysis. Accurate prediction of sea level is important as it affects the natural processes occurring in the basin and influences the infrastructure built along coastlines. Several conventional linear regression methods such as routine Autoregressive Moving Average (ARMA) models, neural network methodologies and artificial intelligence approaches and techniques are included in the study. Based on the results, the authors support the Support Vector Machine as the best performance technique in predicting sea level. Chapter 16 familiarises readers with a novel method of spatio-temporal uncertainty model based on the distribution of gauge rainfall conditioned on radar rainfall (GR|RR). This fully formulated uncertainty model has statistically quantified the characteristics of radar rainfall errors and their spatial and temporal structure. Its spatial and temporal dependencies are simulated based on a Multivariate Distributed Ensemble Generator driven by the copula and autoregressive filter designed including the different wind conditions.

In Chapter 17 authors investigated the bistatic scattering coefficients for the estimation of soil moisture over rough surfaces using fuzzy logic and bistatic scatterometer data at X-band. Linear regression analysis is carried out between scattering coefficients and soil moisture to find the suitable incidence angle for the estimation of soil moisture at HH and VV co-polarization. The last and final Chapter 18 forms the last section of this book, which presented the challenges in geospatial technology for water resources development. This chapter also provide the importance and value of Remote Sensing and Geographical Information System (GIS) in water resources and pointed out the challenges in this field that should be addressed by researchers, policy makers and practitioners in order to view the technology in proper perspective. Several challenges such as monitoring soil, snow and vegetation; soil moisture estimation; monitoring evapotranspiration and energy fluxes; uncertainties in retrieval algorithms; bias associated with instruments; short time spans of satellite data etc are identified that needs to be addressed in near future.

9

CHAPTER

Validation of Hourly GSMaP and Ground Base Estimates of Precipitation for Flood Monitoring in Kumamoto, Japan

Martiwi Diah Setiawati,[1,*] *Fusanori Miura*[1] and *Putu Aryastana*[2]

ABSTRACT

GSMaP (Global Satellite Mapping Precipitation) satellite rainfall estimates are evaluated at the hourly time scales and a spatial resolution 0.1° latitude × 0.1° longitude. The reference data came from AMEDAS (Automated Meteorological Data Acquisition System) station network of about 27 rain gauges over Kumamoto Prefecture, Japan. This region has very complex terrain and humidity which is characterized by typhoon. Hence, this area are often hit by flash flood. The research has been conducted to evaluate hourly GSMaP (i.e., GSMaP_MVK (Moving Vector with Kalman Filter) and GSMaP_NRT (Near Real Time) data with AMEDAS data during flood events from 2003 to 2012 and to define the rainfall pattern which causes flood. Statistical analysis was used to evaluate the GSMaP data, both qualitative and quantitative. The results indicate that GSMaP_MVK was reasonably good at detecting precipitation events and GSMaP_NRT was inadequate to represent the rainfall AMEDAS data. Long term and short term rainfall patterns were observed over Kumamoto Prefecture before the occurrence of the flood.

KEYWORDS: GSMaP, verification, flood, Kumamoto.

❍ INTRODUCTION

Rainfall amount and its spatial distribution are important for flood prediction and water resources assessment (Shrestha et al. 2011). Japan and other countries have been greatly damaged by floods in the past due to heavy rainfall. In addition, Japan is particulary vulnerable to flooding due to its steep topography and humidity characterized by typhoons (Kazama et al. 2009). Moreover, the number of floods in Japan have increased since 2004, especially in the Kyusu region (Kazama et al. 2009). Therefore, a flood forecasting system using rainfall data observed by satellite would be a welcome development. Recently, several kinds of global precipitation satellite data have become available. Some of them have resolutions of one hour and one degree, which may be defined as high temporal and spatial resolution. The GSMaP (Global Satellite Mapping Precipitation) data, as the highest temporal and spatial resolution satellite data, can detect a precipitation event with the same trend as rain gauge data, but the precipitation amount generally has been underestimated (Fukami 2010; Kubota et al. 2009; Makino 2012; Seto et al. 2009; Shrestha et al. 2011). Underestimation of precipitation can cause underestimation of discharge and it causees high bias for flood forecasting (Kabold and Suselj 2005; Pauwels and Lannoy 2005). Hence evaluation of this product is necessary.

Other researchers have shown that GSMaP data products have been verified well in monthly and daily rain gauge data. Shrestha et al. (2011) found that GSMAP_MVK+ performed better in flatter terrain than in the high mountain area over the Central Himalayas. In addition, Kubota et al. (2009) showed that rainfall estimates of GSMaP were the best over the ocean and were the worst over mountainous regions. Seto et al. (2009) noted that monthly GSMaP data had been verified well in Japan, so GSMaP data seemed to be good enough for flood detection.

GSMaP_MVK was verified from January through December 2004 in Japan to determine whether monthly data, daily data and 3 hourly data matched rain gauge data. The result showed that GSMaP_MVK of monthly, daily and 3 hourly data from May to October had 0.7, 0.7 and 0.6 of correlation coefficient and had the same trend as rain gauge data (Kubota et al. 2009). Although monthly, daily and 3 hourly data have been verified, hourly GSMaP data have not yet been verified especially in Kyushu, Japan. Hourly rainfall data is important to understand the rainfall pattern, especially when extreme rainfall occurs. The aims of this research were to verify hourly GSMaP data with rain gauge data and to define the rainfall pattern which causes flood.

❍ METHOD

Study Area

Kumamoto Prefecture is located in the west central Kyushu Island, Japan. The study area covers an area of 389.53 km^2 from latitude 32°5′45″ N to 33°6′17″ N and longitude 129°59′8.75″ E to 131°19′7.7″ E. Kumamoto has a humid subtropical climate and has an elevation ranging from 2 mto 1193 m above the sea level. Precipitation occurs throughout the year with the heaviest in the summer season, especially in the months of June and July. In the summer season from 1981 to 2010, the variability of temperature range was from 12.23°C to 37.5°C and the average of precipitation was 326.4 mm/month.

Data Sets

GSMaP Data

GSMaP was initiated by the Japan Science and Technology Agency (JST) in 2002 and has been promoted by the Japan Aerospace Exploration Agency (JAXA) Precipitation Measuring Mission (PMM) science team since 2007 to produce a global precipitation product with high temporal and spatial resolution (Ushio et al. 2009). The GSMaP product is the combination from low orbit multi satellite microwave radiometer data, such as Tropical Rainfall Measuring Mission Microwave Imager (TRMM TMI), AQUA Advance Microwave Scanning Radiometer (AMSRE), Advance Earth Observing Satellite (ADEOS) II AMSRE and Defense Meteorological Satellite Program Special Sensor Microwave Imager (DMSP SSM/I) and Geosyncronous Orbit (GEO) infra red radiometer data (Okamoto et al. 2007). Brightness temperature at microwave frequencies as the input of GSMaP system was converted into precipitation data. The algorithm to regain surface precipitation rate based on the Aonashi et al. 1996 study was conducted. The combination technique to produce 0.1 degree/1 hour resolution with the domain covering 60° N to 60° S was obtained using a morphing technique using an infra red cloud moving vector and Kalman Filter technique (Ushio et al. 2009). This product was called GSMaP_MVK. GSMaP_MVK version 5 were used in this study.

GSMaP_NRT (near real time) is one of GSMaP products which uses the same algorithm as GSMaP_MVK and after four hours of observation, data can be obtained (EORC and JAXA 2013a). GSMaP_MVK version 5 data are available from March 2000 until December 2010 while GSMaP_NRT are available from October 2008 until now. Hourly data of GSMaP_MVK and GSMaP_NRT for two weeks before the flood occurrence in the past 10 years in Kumamoto Prefecture were downloaded. Both GSMaP_MVK and GSMaP_NRT were processed by using Open GRADS software. Point by point analysis was conducted to compare between rain gauge data and satellite data. This method was also applied by As-syakur et al. 2011.

Rain Gauge Data

Hourly observed rainfall data in Kumamoto Prefecture was obtained from AMEDAS (Automated Meteorological Data Acquisition System) data which was developed by the Japan Meteorological Agency (JMA). There are 36 rain gauge stations available in Kumamoto Prefecture, but only 27 rain gauge stations were used. These data are available online on the JMA website (http://www.data.jma.go.jp) and the distribution of the rain gauge stations is shown in Fig. 1. Rain gauge data which represent the rainfall at the point were used as reference in our comparison. The point-by-point analysis conducted to compare rain gauge data and satellite data is shown in Fig. 2. As-syakur et al. (2011) and Prasetia et al. (2013) also applied this method. Opengrads software was used to adjust the rain gauge data and satellite data. Table 1 summarizes the major specifications of rainfall data for GSMaP product and rain gauge data. We analyzed both data products which have the same temporal resolution that is 1 hour. The GSMaP product domain is 60°N-60°S, but in this research only Kumamoto Prefecture was analyzed. AMEDAS data are available from November 1974 until now and the separation distance of each rain gauge is approximately 21 km.

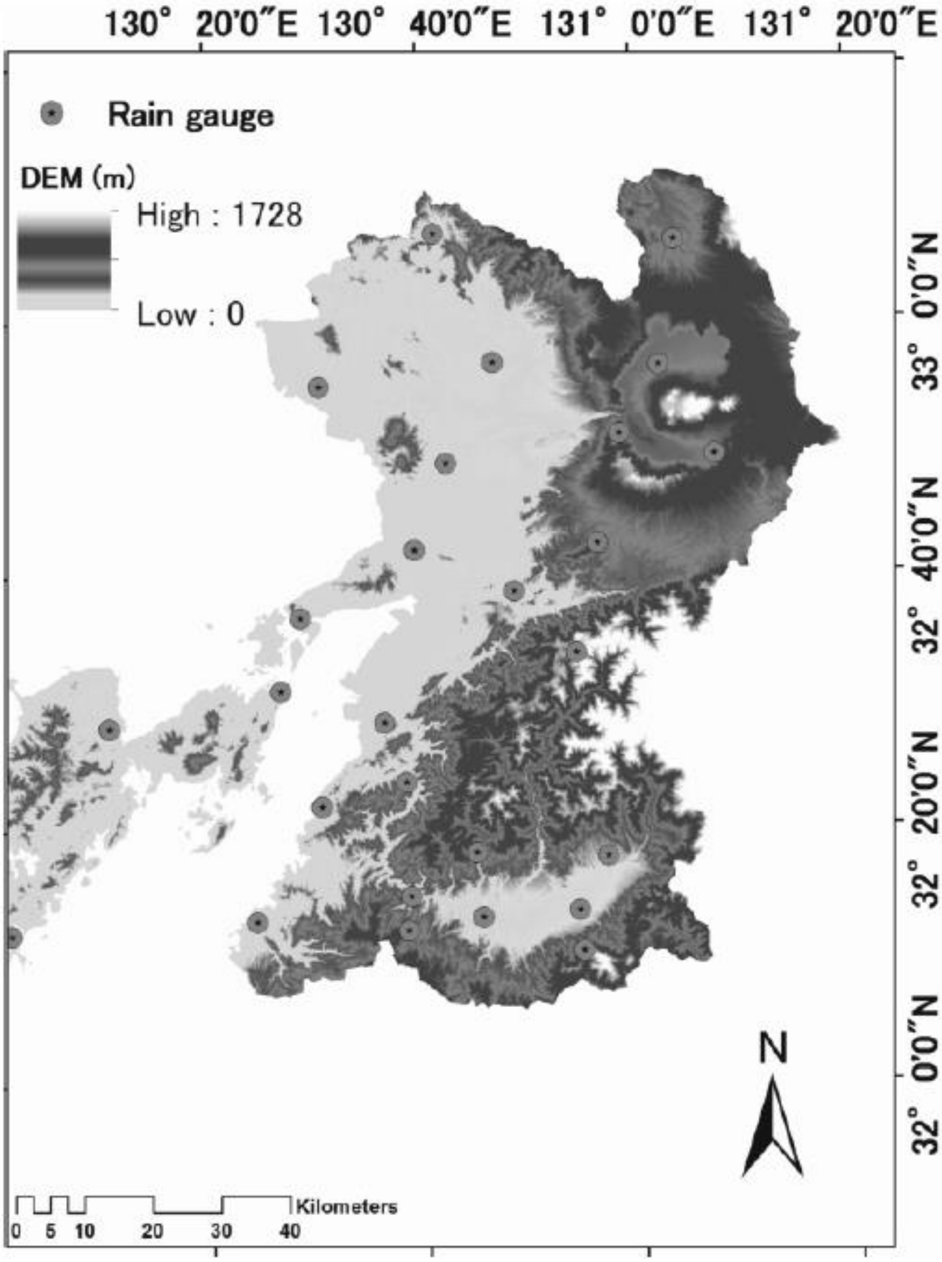

Figure 1 Distribution of 27 rain gauge stations in Kumamoto Prefecture.

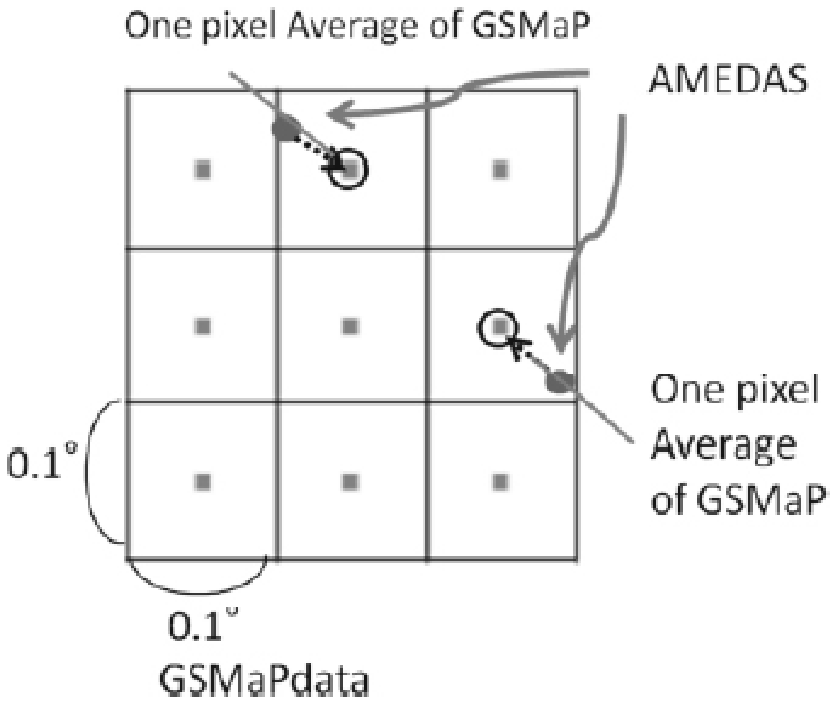

Figure 2 Point by point analysis.

TABLE 1 Detail product.

Product	Temporal resolution	Spatial resolution	Start date	Delay
GSMaP	1 hour	0.1 × 0.1 degree	March 2000	4 hour
Rain gauge	1 hour	Single point	November 1974	

Time Series Graph

A time series graph was conducted to estimate the rainfall pattern before the flood occurrence and to estimate the time lag between GSMaP precipitation data and observed rainfall data.

Verification Method

Visual Verification

There are several verification methods which can be used; one of them is visual verification. In this method, formatting the single point of rain gauge data sets into the spatial distributions with the same projection and the same color scale with GSMaP datasets was conducted. ArcGIS 10.1 was used as a tool to convert the single point data set into a raster data set, by using the kriging spatial interpolation method. The spherical model of kriging interpolation was chosen because of the very high correlation coefficient (0.9) with the observed rain gauge data. This method was used to convert the daily point gauge observed rainfall data to a 0.1 degree latitude/longitude grid. Gridded precipitation data from the ground station was used for visual comparison with GSMaP precipitation data.

Continuous Statistics

The aim of this method was to measure the correspondence between value of the estimates and the observation. To quantify the correspondence value, the following five statistical indices were used (Jiang et al. 2010). The correlation coefficient (r) was used to measure the fitness between GSMaP precipitation data and rain gauge observations which are shown in equation 1 (eq. 1). The Root Mean Square Error (RMSE) measured the average error magnitude (eq. 2). The mean absolute error (MAE) measured the average difference between GSMaP precipitation data and observed values (eq. 3). The relative bias (B) described the systematic bias of the satellite precipitation (eq. 4). The Nash-Sutcliffe (C_{NS}) measured the consistency of the satellite precipitation and gauge observation, both amount and temporal distribution (eq. 5). These indices are given by following equations.

$$r = \frac{\sum_{i=1}^{n}(G_i - \bar{G})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(G_i - \bar{G})^2}\sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}} \quad (1)$$

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - G_i)^2} \quad (2)$$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|S_i - G_i| \quad (3)$$

$$B = \frac{\sum_{i=1}^{n}(S_i - G_i)}{\sum_{i=1}^{n}G_i} \times 100\% \quad (4)$$

$$C_{NS} = 1 - \frac{\sum_{i=1}^{n}(S_i - G_i)^2}{\sum_{i=1}^{n}(G_i - \bar{G})^2} \quad (5)$$

where n is the total number of the rain gauge data or GSMaP data; S_i is the satellite estimates and G_i is the rain gauge observation values.

Categorical Statistics

Categorical statistics are used to measure the correspondence between the estimated and observed occurrence of events. Two categorical statistics were used, namely, the probability of detection (POD) and the false alarm ratio (FAR). POD measured how often the rain occurrence was correctly detected by satellite. FAR represented the fraction of diagnosed events that turned out to be wrong. Table 2 summarizes the contingency to assess GSMaP rainfall detection capability with rain or no rain events. The threshold of rain/no rain used in the contingency table is 0 mm/hour. In Table 1, "hits" represents correctly estimated rain events, "misses" describes when rain is not estimated but actual rain occurs, "false alarm" represents when rain is estimated but actual rain doesn't occur and "correct negative" represents correctly estimated no-rain events. Using the results shown in Table 2, the parameters POD and FAR are calculated by following equations.

$$POD = \frac{hits}{hits + misses} \quad (1)$$

$$FAR = \frac{false\ alarm}{hits + false\ alarm} \quad (2)$$

TABLE 2 Contingency table of yes or no events/with rain or no rain.

Observed rainfall	Estimated rainfall	
	Yes	No
Yes	hits	misses
No	false alarm	correct negative

RESULT AND DISCUSSION

History of Floods in Kumamoto Prefecture

Between 2003 and 2013, there were nine flood eventsoccurred in Kumamoto Prefecture. Flood mostly occurs in June or July, which is the rainy season in Japan. The floods spread mostly in the low altitude as shown in Fig. 3, except in Asootohime. During that period, Yamato city was hit by flood two times (2006 and 2007) and the highest flood frequency was in 2007 (four times). The floods occurred when the heavy rain was ranging from 221 mm/week to 608 mm/week. Extreme rainfall occurred in 2003 and 2012 and caused flash flooding and landslides. As a result, in 2012, 28 deaths were reported from this event with thousands forced to evacuate fast and widespread property damage.

Time Series Graph

There were two kinds of rainfall pattern which caused flood, namely, a long term pattern and a short term pattern. The long term pattern refers to accumulative rainfall from one day to several days causing flood. The short term rainfall pattern refers to accumulative rainfall for several hours causing flood.

Long Term Pattern

Figs. 4a and b shows the rainfall pattern before the flood occurrence in Gyuto city. The black line indicates hourly observed rainfall by AMEDAS while the orange line indicates hourly rainfall estimates by GSMaP_MVK. The pattern of both rainfall data was similar, but there was a time lag of 9 hours. From this result, it seems that GSMaP_MVK was able to predict the rainfall occurrence around Kumamoto Prefecture for flood monitoring because GSMaP_MVK can observe the amount of rainfall nine hours earlier.

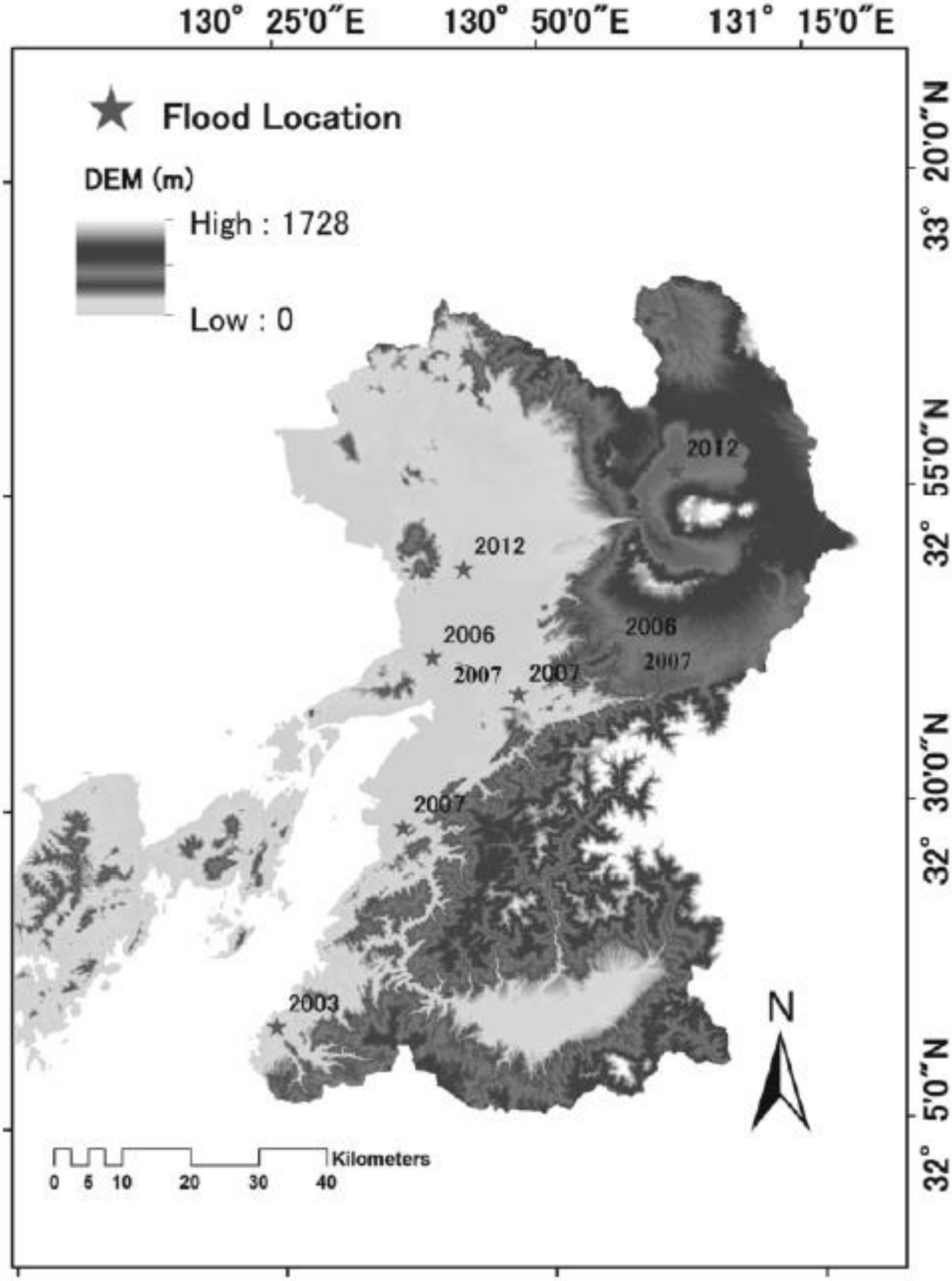

Figure 3 Flood occurrence during 2003 to 2013 in Kumamoto Prefecture.

Fig. 4b shows the rainfall pattern for AMEDAS data and GSMaP_MVK data after time lag calculation. In general, rainfall data from GSMaP_MVK were lower than rain gauge data especially during extreme rainfall (i.e. the highest rainfall amount of AMEDAS data was 50 mm/hr while in the same time the GSMaP_MVK data was 9 mm/hr). In addition, the total amount of rainfall which trigger the flash flood in the Gyuto city was 422 mm/week. This result shows that the rainfall pattern

[Fig. 4b](#) shows the rainfall pattern for AMEDAS data and GSMaP_MVK data after time lag calculation. In general, rainfall data from GSMaP_MVK were lower than rain gauge data especially during extreme rainfall (i.e. the highest rainfall amount of AMEDAS data was 50 mm/hr while in the same time the GSMaP_MVK data was 9 mm/hr). In addition, the total amount of rainfall which trigger the flash flood in the Gyuto city was 422 mm/week. This result shows that the rainfall pattern before the flood occurred was almost same and is classified as long term rainfall period because it took several days to trigger flash flood. Moreover, long term rainfall pattern occurred in 2007 and 2006 in Yatsushiro city, Yamato city, Mifune city, Misato city and Misato city. In those events, the total amount of rainfall in a week ranged from 406 mm to 608 mm.

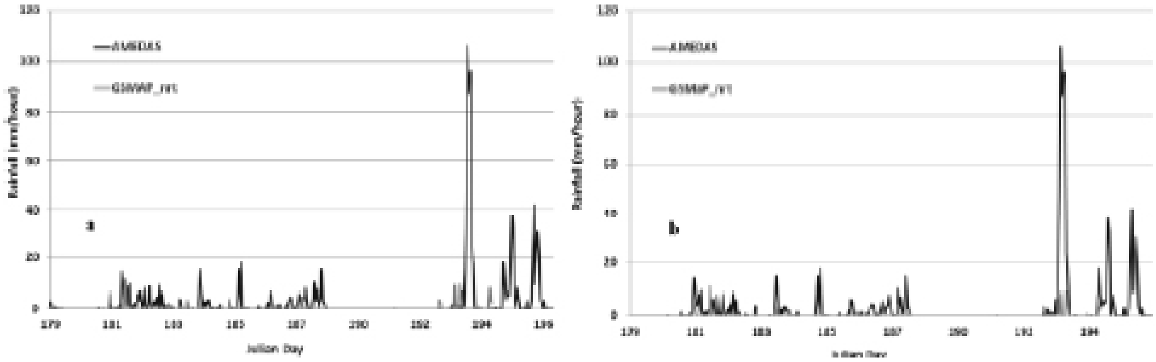

Figure 4 Rainfall pattern before the flood occurred in Gyuto city, 25 July 2006 (a); and after time lag matching (b).

Short Term Pattern

The most recent flood occurred in Kumamoto Prefecture was on 12 July 2012. GSMaP_MVK is only available from 2000 to 2010, therefore GSMaP_NRT was chosen as a satellite precipitation data in this research. Both GSMaP_NRT and GSMaP_MVK have same algorithm, but GSMaP_MVK is the reanalysis version of GSMaP_NRT (EORC & JAXA 2013a). Fig. 5a shows the rainfall pattern before the flood occurrence in Kumamoto city. The black line indicates hourly observed rainfall by AMEDAS while the orange line indicates hourly rainfall estimates by GSMaP_nrt. The pattern between AMEDAS data and GSMaP data is hard to recognize, but the rainfall occurrence can be detected. The GSMaP_NRT value underestimated rainfall and the time lag with AMEDAS data was 9 hours earlier. GSMaP_NRT still has a possibility to detect the rainfall occurrences as explained later. The time series graph after time lag matching is shown in Fig. 5b.

Fig. 5b shows the rainfall pattern of two weeks difference and looks similar in the 12 July 2012. A short term rainfall pattern occurred in this city. On 12 July 2012, heavy rainfall occurred for 5 hours with the peak rainfall amount of 435 mm for 5 hours. Asootohime at high altitude had heavy rainfall of 435.5 mm for 5 hours. As a consequence, a flash flood hit Asootohime city for the first time after 30 August 1980. This disaster caused 25 people dead/missing and 385 destruction of house and public facility (Yokota et al. 2014). In addition, the short term rainfall pattern had a rainfall amount ranging from 199 mm to 435 mm for 5 hours. Because of this pattern, measurement of high temporal resolution of precipitation data became very important. However, the uncertainty precipitation is the main source of uncertainty impacting on the flood forecasts (Nester et al. 2012). Thus, the several approaches should be used to measure rainfall characteristics. One approach is to use precipitation satellite data which is easy to get, has high temporal resolution data and can easily reach isolated areas. For that reason, verification of hourly precipitation satellite data is necesssary.

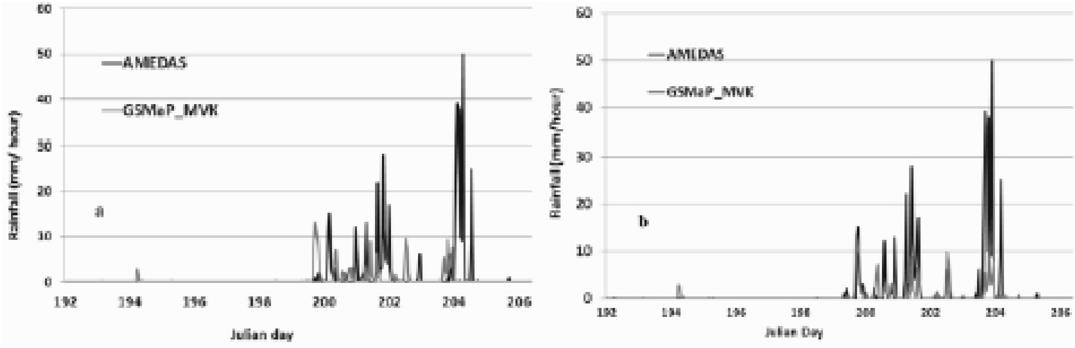

Figure 5 Rainfall pattern before the flood occurred in Asootohime city, 12 July 2012 (a); and after time lag matching (b).

VISUAL VERIFICATION

Fig. 6 shows visual verification of GSMaP_MVK data after 9 hours time lag matching. It shows that the spatial distribution was almost same in the northern part of Kumamoto Prefecture when the light rain came. In contrast, the spatial distribution difference occurred when heavy rain comes (i.e heavy rains was recorded in the eastern part of the study area by AMEDAS, but it was recorded in the southeastern part of the sudy area by GSMaP_MVK). However, the GSMaP_MVK data still underestimated the actual rainfall. Fig. 7 shows visual verification of GSMaP_NRT data after 9 hours time lag matching. It shows that the spatial distribution was different and that the GSMaP_NRT data also underestimated actual rainfall. The highest concentration of GSMaP_NRT data in Fig. 7 was between 10 to 15 mm/hr.

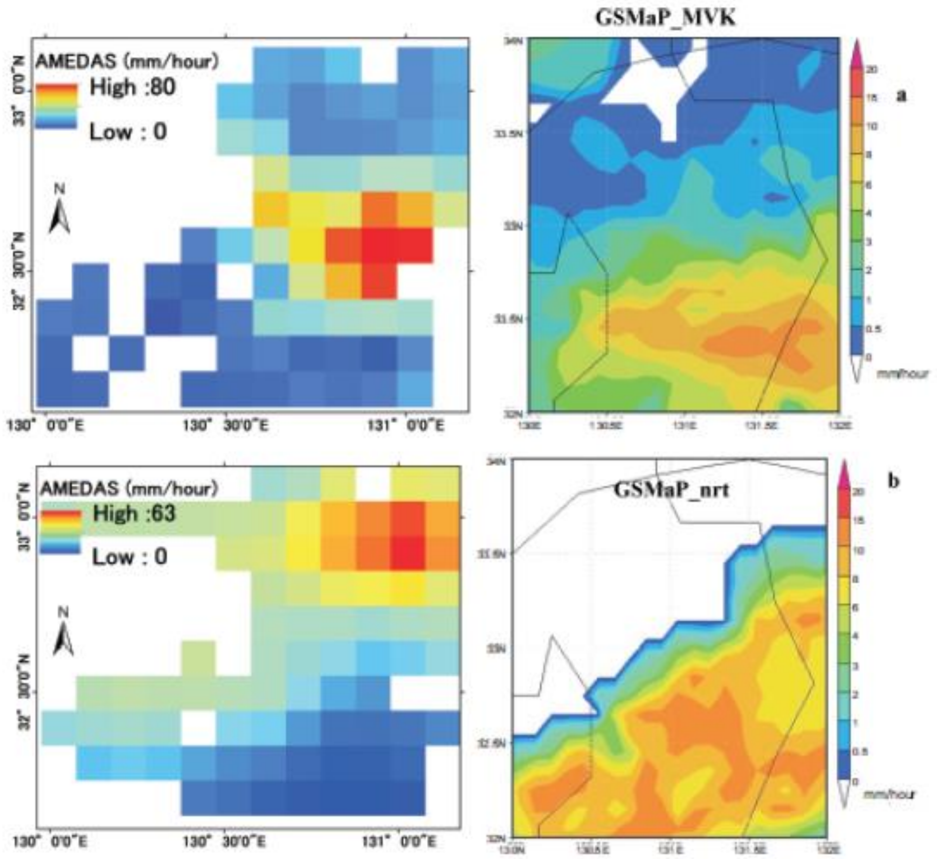

Figure 6 (a) Spatial distribution of observed rainfall 6 July 2007 at 09.00 (left) and rainfall estimates by GSMaP_MVK 6 July 2007 at 00.00 (right) (b) Spatial distribution of observed rainfall 12 July 2012 at 06.00 (left) and rainfall estimates by GSMaP_NRT 11 July 2012 at 22.00 (right).

Statistical Verification

GSMaP_MVK

Fig. 8 shows the validation result of GSMaP_MVK in Kumamoto Prefecture. The value of the five continuous statistics showed that GSMaP_MVK was reasonably good at detecting precipitation events before the flood occurrence. For the area averaged hourly rainfall, the correlation coefficient was 0.52, RMSE was 5.148 mm/hr with the bias percentage of –54.09% indicating an underestimation of rainfall. The underestimation of rainfall is consistent with the previous finding (Fukami et al. 2010; Kubota et al. 2009; Seto et al. 2008; Shrestha et al. 2011). Underestimation of GSMaP data resulted from no microwave radiometer information during the peak period for heavy rainfall (Kubota et al. 2009) and sudden increases in rain rate did not reflect the IR brightness temperature (Ushio et al. 2009). In Kumamoto Prefecture, hourly GSMaP_MVK data has a weak correlation coefficient compared with the previous study which validated daily GSMaP_MVK data (Makino 2012). Table 3 shows the result of categorical statistics for which 2312 total points were observed. Hits frequency was 446 times, misses frequency was 135 times, false alarm frequency was 277 times and correct negative frequency was 1454 times.

TABLE 3 Contingency table of yes or no events/with rain or no rain of GSMaP_MVK.

AMEDAS	GSMaP_MVK	
	Rain	No rain
Rain	446	135
No rain	277	1454

POD: 0.768; FAR: 0.383

Based on Table 3, POD and FAR value were 0.77 and 0.38. It means that 77% of rain occurrences were correctly detected and 38% of rain occurrences turned out to be wrong by GSMaP_MVK. These values of two categorical statistics showed that GSMaP_MVK product was reasonably good at detecting the precipitation events over Kumamoto Prefecture.

GSMaP_NRT

Fig. 8 shows the validation result of GSMaP_NRT in Kumamoto Prefecture. The value of the five continuous statistics showed that GSMaP_NRT was not good at detecting precipitation events before the flood occurred. For the area averaged hourly rainfall, the correlation coefficient was 0.24 RMSE was 8.272 mm with the bias percentage of –87.042% indicating underestimation of rainfall. Table 4 shows the result of categorical statistics which 716 total points were observed. Hits frequency

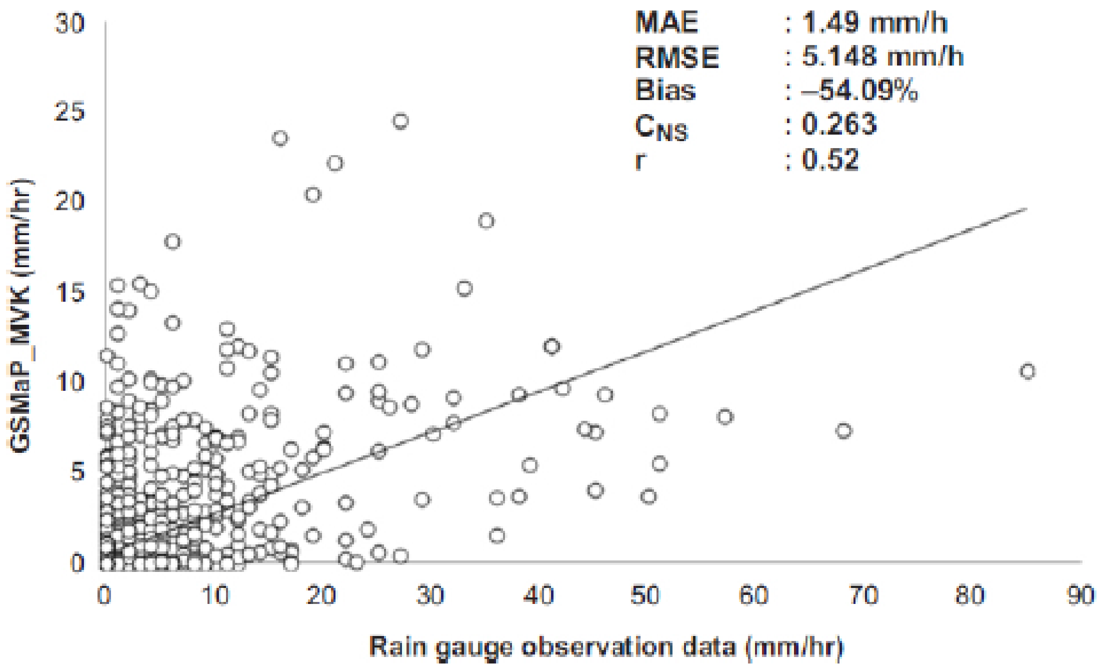

Figure 7 Scatter plot of rain gauge observation and GSMaP_MVK hourly scales in Kumamoto Prefecture.

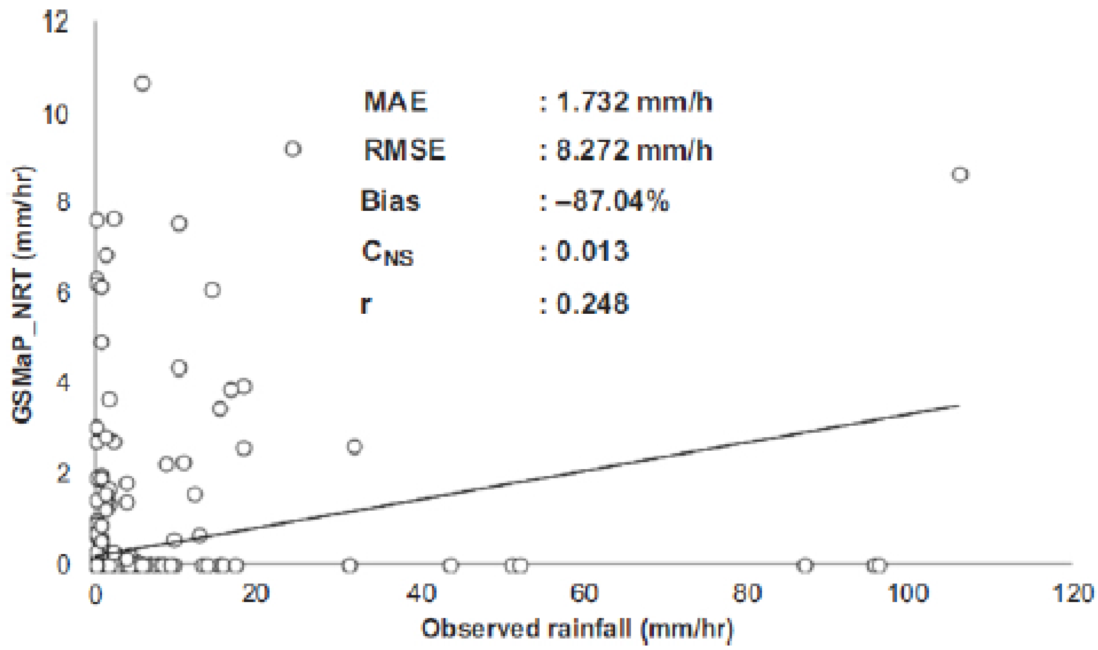

Figure 8 Scatter plot of rain gauge observation and GSMaP_NRT hourly scales in Kumamoto Prefecture.

TABLE 4 Contingency table of yes or no events/with rain or no rain of GSMaP_NRT.

AMEDAS	GSMaP_NRT	
	Rain	No rain
Rain	76	137
No rain	37	466

POD: 0.357; FAR: 0.327

Based on Table 4, POD and FAR values was 0.357 and 0.327. It means 35.7% of rain occurrences were correctly detected and 32.7% of rain occurrences turned out to be wrong by GSMaP_NRT. These values of two categorical statistics showed that GSMaP_NRT product was not so good at detecting the precipitation events in Kumamoto Prefecture. Nevertheless, GSMaP_NRT has the value of FAR similar with GSMaP_MVK and can be downloaded after 4 hour satellite observation. As a result, GSMaP_NRT can be used as emergency data analysis for precipitation data when rainfall observation data is not available.

❍ CONCLUSIONS

There were two rainfall patterns over Kumamoto Prefecture before the flood occurrence, namely "the long term period" and "the short term period". In the long term period, the flood occurred when the rainfall amount ranged from 406 mm to 608 mm for one week, while the short term period was from 199 to 435 mm for five hours. GSMaP_MVK was reasonably good at detecting precipitation events before the flood occurrence both spatially and temporally. GSMaP_NRT was not good at detecting precipitation events before the flood occurrence, especially for spatial distribution, but it can be used as emergency data analysis for precipitation data when rainfall observation data is not available. For the future research, evaluation and bias correction of GSMaP data during rainy season is necessary to reduce the error, especially during heavy rainfalls.

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[1] Graduate School of Environmental Science and Engineering, Yamaguchi University, Tokiwadai, Ube, Yamaguchi, Japan.

[2] Civil Engineering Department, Warmadewa University, Denpasar, Indonesia.

* Corresponding author: s503wf@yamaguchi-u.ac.jp, martiwi1802@gmail.com