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Restricting urban sprawl through multifunctional urban agriculture at the fringe of the Jabodetabek Metropolitan Area: a multilevel study

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“The ultimate goal of farming is not the growing of crops, but the cultivation and perfection of human beings.”

(Masanobu Fukuoka, The One-Straw Revolution, 2006).

CONTENT

List of Publication

The following four research papers present the basis of this cumulative dissertation. At the time of the thesis submission two of them have been already published, and two are within the process of review.

1. Pribadi, D.O., Pauleit, S., 2015. The dynamics of peri-urban agriculture during rapid urbanization of Jabodetabek Metropolitan Area. *Land Use Policy* 48: 13-24.

2. Pribadi, D.O., Pauleit, S., 2016. Peri-urban agriculture in Jabodetabek Metropolitan Area and its relationship with the urban socioeconomic system. *Land Use Policy* 55:265-274

3. Pribadi, D.O., Vollmer, D., Pauleit, S., in review. Understanding the impact of peri-urban agriculture in rapidly developing city regions on runoff and soil erosion. *Regional Environmental Change*.

4. Pribadi, D.O., Zasada, I., Müller, K., Pauleit, S., in review. Multifunctional adaptation of farmers as response to urban growth in the Jabodetabek Metropolitan Area, Indonesia. *Journal of Rural Studies*.

My contributions to the research papers enclosed in this doctoral thesis were as follows:

Paper 1: Development of main conceptual idea and analytical framework; field survey for land use analysis; data processing and statistical analysis; and writing the results and discussion in collaboration with the coauthor.

Paper 2: Development of main conceptual idea and analytical framework; data processing, statistical analysis, and development of the spatial heterogeneity model; writing the results and discussion in collaboration with the coauthor.

Paper 3: Development of main conceptual idea and analytical framework; in collaboration with the coauthors developed an approach to assess the effect of agricultural land use changes on runoff and soil erosion and to define agricultural management zones to control the effect; writing the results and discussion in collaboration with the coauthors.

Paper 4: Development of main conceptual idea and analytical framework; in collaboration with the coauthors design of a questionnaire for doing interviews with the farmers; data processing and statistical analysis; writing the results and discussion in collaboration with the coauthors.

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List of Abbreviations

BPS	Badan Pusat Statistik (The Central Statistic Agency)
CA	Correspondence Analysis
CBR	Cost Benefit Ratio
DEM	Digital Elevation Model
ETM+	Enhanced Thematic Mapper Plus (Landsat)
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographical Information System
GWR	Geographically Weighted Regression
Jabodetabek	Jakarta Bogor Depok Tangerang Bekasi
JMA	Jabodetabek Metropolitan Area
KSN	Kawasan Strategis Nasional (National Strategic Region)
MSS	Multi-spectral Scanner (Landsat)
PCA	Principal Componenent Analysis
PODES	Data Potensi Desa (Village Potency Data)
PSP3	Pusat Studi Pembangunan Pertanian dan Perdesaan
PUA	Peri-urban Agriculture
RIHN	Research Institute for Human and Nature
RTRWN	Rencana Tata Ruang Nasional
RUAF	Resource Centres on Urban Agriculture and Food Security
SCS	Soil Conservation Services
SDUH	Spatially Distributed Hydrograph
SRTM	Shuttle Radar Topography Mission
Susenas	Survei Sosial Ekonomi Nasional (The National Social-Economic Survey)
TM	Thematic Paper (Landsat)
TNP2K	Tim Nasional Percepatan Penanggulangan Kemiskinan (The National Task Force for Poverty Alleviation)
UNDP	United Nations Development Program
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
USLE	Universal Soil Loss Equation

SUMMARY

Rapid urbanization in Asia has led to the phenomenon of urban sprawl, i.e. low density and leapfrog development, that puts strong pressure on densely populated agricultural land in the peri-urban zone. It has created a specific feature called “desakota” where urban and rural systems are intermingled and cause economic, social, and environmental conflicts. While it is regarded as a temporary phenomenon during the urbanization process, emerging issues of food security, urban poverty, and environmental degradation have made the management of the mix of urban and rural land uses within the peri-urban region a crucial issue. Unfortunately, the rural-urban dichotomy in planning exacerbates the conflict, while policies for promoting urban-rural linkages failed to be applied due to the complexity of the desakota system. The urban agriculture concept has a potential to overcome the conflict between the needs for urban development, enhancement of food security, poverty alleviation, and improvement of environmental quality in peri-urban regions, as it focuses on developing multi-functionality and connectivity of agriculture with the urban system. Therefore, this dissertation aims to explore the potential of peri-urban agriculture (PUA) to support sustainable development of Jabodetabek Metropolitan Area (JMA) as one of the biggest megacities in Asia.

The *first paper* investigates the dynamics of PUA during the urbanization process in JMA and how each PUA type adapts differently to urbanization. This paper is important to define the roles of PUA within the socioeconomic and ecological system of JMA. Furthermore, as PUA types show varying responses to urbanization, the *second* and *third papers* focus on more detailed analysis to identify the socioeconomic and ecological effect of PUA types in different areas of JMA. PUA zones are distinguished that should be managed to enhance the capacity of JMA in dealing with food security, poverty, and urban informality as part of socioeconomic issues, and increasing runoff and soil erosion as part of environmental issues. The results from these studies will support urban planners to acknowledge PUA as a part of the urban land use system. Moreover, in order to enhance the management of PUA zones, the characteristics of farming businesses need to be understood. Therefore, the *fourth paper* analyzes the factors that influence farmers’ decision making to develop multifunctional agriculture as a key to integrate PUA into urban planning policy.

Key findings indicate that PUA in JMA keeps persisting during rapid urban expansion and even has played an important role in food provision in a crisis situation. Some PUA types (e.g lowland horticulture, inland aquaculture) exist in the smaller and fragmented land between urban settlements as they can benefit from the proximity to the urban market. Other PUA types (e.g paddy and food crops, upland horticulture, livestock) have been pushed outward by urbanization. The different potential for adaptation of PUA types has led to a variable capacity of PUA in specific areas of JMA to deal with food security, poverty, and informality, as well as runoff and soil erosion problems in JMA. Still, the expansion of PUA should be controlled as it threatens forest land which is also important for maintaining hydrological functions of water catchment areas in JMA. Furthermore, PUA zones which have different functions should be supported by the application of multifunctional practices at the farm level. Farmers' decision to apply activities beyond food and fiber production depends on their individual characteristics, farming motives, and land tenure situation. Therefore, policies for PUA should be able to address both the management of PUA zones and their functions in a city / local level and the development of multifunctional practices at the farm level.

ZUSAMMENFASSUNG

Rapide Verstädterung hat in Asien zu dem Phänomen der städtischen Zersiedelung geführt, die sich beispielsweise durch eine geringe Bebauungsdichte oder das so genannte „leapfrog development“ auszeichnet. Hierdurch wird ein hoher Druck auf die dicht besiedelten landwirtschaftlich geprägten Gebiete der Stadtrandzone. Die sich daraus ergebende Vermischung urbaner und ländlicher Systeme wird als “desakota” bezeichnet, welche ökonomische, soziale und ökologische Konflikte mit sich bringt. Während diese Vermischung im Rahmen des Urbanisierungsprozesses als temporäres Phänomen eingestuft wird, machen neu auftretende Problemfelder wie Nahrungsmittelknappheit, städtische Armut und Umweltzerstörung das Management dieser urban-rural gemischten Landnutzung innerhalb vorstädtischen Regionen zu einer bedeutenden Aufgabe. Unglücklicherweise verschärft diese Dichotomie der Planungsprozesse den Konflikt und mittlerweile sind auch die Bemühungen zur Unterstützung rural-urbaner Vernetzungen aufgrund der Komplexität des “desakota”-Systems gescheitert. Ein urbanes Landwirtschaftskonzept birgt das Potenzial, die Unvereinbarkeit zwischen der Notwendigkeit urbaner Entwicklung, der Verbesserung von Nahrungsmittelversorgung und Umweltqualität und der Armutsbekämpfung in den Stadtrandzonen zu beheben, indem die Multifunktionalität und Anschlussfähigkeit der Landwirtschaft an das urbane System gestärkt werden sollen. Die vorliegende Dissertation widmet sich der Analyse des Potenzials der stadtnahen Landwirtschaft (engl. peri-urban agriculture, PUA) als Grundlage zur Unterstützung einer nachhaltigen Entwicklung in der Metropolregion Jabodetabek (JMA), einer der größten Megacities in Asien.

Der *erste Aufsatz* untersucht die Dynamik von PUAs während des Verstädterungsprozesses der JMA und wie sich unterschiedliche Typen von PUAs in diesen Prozess einfügen. Diese Analyse ist notwendig um den Stellenwert der PUAs im sozioökonomischen und ökologischen System der JMA zu verstehen. Aufgrund der Tatsache, dass PUAs unterschiedliche Reaktionen auf Verstädterungsprozesse aufweisen, beinhalten die A*ufsätze 2* und *3* eine detaillierte Analyse ihrer sozioökonomischen und ökologischen Effekte in unterschiedlichen Gebieten der JMA. Verschiedene PUA-Zonen werden definiert, die dazu genutzt werden sollen um die Kapazitäten der JMA hinsichtlich der Bekämpfung von Nahrungsmittelknappheit, Armut und urbaner Schattenwirtschaft als Teil sozioökonomischer, beziehungsweise von zunehmenden Abfluss- und Erosionsraten als Teil ökologischer Aspekte zu stärken. Die Ergebnisse liefern ein positives Argument für Stadtplaner, PUAs als Teil des urbanen Landnutzungssystems zu würdigen. Darüber hinaus

müssen die Charakteristika der landwirtschaftlichen Gewerbe besser verstanden werden, damit das Management der unterschiedlichen PUA-Zonen verbessert werden kann. Diesbezüglich widmet sich der *vierte Aufsatz* den Faktoren, die Entscheidungsprozesse von Landwirten beeinflussen, um multifunktionale Landwirtschaft etablieren zu können, die ein Schlüssel für die Integration von PUAs in urbane Planungspolitik ist.

Die wesentlichen Ergebnisse der Arbeit zeigen, dass PUA in der JMA im rasanten Urbanisierungsprozess bestehen bleibt und sogar in einer Krisensituation eine bedeutende Rolle für die Versorgung mit Lebensmitteln gespielt hat. Manche PUA-Typen, wie z.B. Tiefland-Gartenbau und Inland-Aquakultur, existieren in kleineren und zersplitterten Gebieten zwischen urbanen Siedlungen, da sie von der Nähe zum städtischen Markt profitieren können. Andere Typen, wie z.B. Reisfelder, Feldfrucht-Kulturen, Hochland-Gartenbau und Viehzucht, wurden infolge von Urbanisierung nach außen verdrängt. Die verschiedenen Adaptionspotenziale der PUA-Typen zeigen ihre unterschiedlichen Kapazitäten, innerhalb spezifischer Gebiete der JMA positiv zu Nahrungsmittelversorgung, Armuts- und Schattenwirtschaftsbekämpfung, als auch zur Eindämmung von Abflussspitzen und Bodenerosion beizutragen. Dennoch sollte die Expansion der PUAs einer Kontrolle unterliegen, da sie Waldland gefährden, welches ebenso notwendig ist für die Erhaltung der hydrologischen Funktionen von Wassereinzugsgebieten der JMA. Darüber hinaus ist eine Förderung von PUAs mit unterschiedlichen Funktionen durch die Anwendung multifunktionaler Praktiken auf Ebene der Farmen sinnvoll. Die Entscheidungen der Landwirte, ihren Tätigkeitsbereich über die Nahrungsmittel- und Holzproduktion hinaus zu erweitern, ist abhängig von ihren individuellen Eigenheiten, Anbaumotiven und Besitzstrukturen. Daher sollten Konzepte für PUAs sowohl das Management der Zonen und ihre Funktionen in der jeweiligen Stadt bzw. auf lokaler Ebene, als auch die Entwicklung multifunktionaler Praktiken auf Ebene der Farmen berücksichtigen.

1 INTRODUCTION

1.1 Research Background and Objectives

Urbanization has led to urban sprawl phenomenon, i.e. low density and leapfrog development, as one of the most serious problems worldwide (Angel et al., 2005; UN-Habitat, 2010a). The expansion of built up areas has converted fertile agriculture land and natural areas and deteriorated environmental conditions. Urban sprawl is particularly severe in urbanizing areas of the developing world due to their rapid growth which is often combined with a lack of planning (Laquian 2008, UN-Habitat, 2010b). Notably, megacities with more than 10 million inhabitants keep growing to form mega-urban regions that encompass cities, town, villages, and rural areas in the form of planned and unplanned urban corridors (UN-Habitat and UNESCAP, 2015). Nowadays, Asia alone has 17 megacities and it is predicted that this region will have no less than 22 megacities in 2030 (UN Habitat and UNESCAP, 2015), while according to another source (UN, 2014), half of the 41 megacities of the world will be located in Asia to accommodate 651 million inhabitants in 2030. Seemingly, the future urbanization in Asia will be characterized by the development of megacities (Blum, 2015; Legget, 2015).

The Asian variant of urban sprawl is distinctive and termed desakota (McGee, 1991). It comes from Indonesian languages where “desa” means village and “kota” means city. Desakota results from the penetration of urban areas into agricultural land use in emerging peri-urban zones that already have dense rural populations due to labor intensive agricultural activities such as paddy rice farms. As a result, rural and urban livelihoods, communication, transport and economic systems are closely intermingled (Moench & Gyawali, 2008) to form a seemingly chaotic land use pattern (Yokohari et al., 2000). Here, the city is not really expanding, but its neighboring countryside is transformed into a specific kind of semi-urban fabric (Meeus and Gulinck, 2008).

Some scholars have regarded desakota as a temporary phenomenon in the urbanization process (Dick and Rimmer, 1998; Hudalah and Firman, 2012). However, emerging issues of gas and food price volatility in the world market coupled with global climate change have emphasized the important role of agricultural land near cities (McGee, 2010). In addition, increasing urban poverty, food insecurity, as well as environmental and quality of live degradation have become major issues in Asian megacities that should be addressed (Dahiya, 2012; Singh, 2015). Recent research indicates that farmland in urban and peri-urban settings has the potential to provide income for the poor (Bryld, 2003; Zezza and Tasciotti, 2010); strengthen food security especially for underprivileged urban dwellers (Altieri et al., 1999; Aubry et al., 2012; Paül and McKenzie, 2013); and improve environmental quality by contributing to climate regulation (Lovell, 2010; Ives and Kendall, 2013), management of water resources (Haase and Nuissl, 2007), flood protection (Kenyon et al., 2008; Weather and Evans, 2009; Aubry et al., 2012); biodiversity conservation (Ives and Kendall, 2013), and provision of outdoor spaces for recreation (Yang et al., 2010; Brinkley, 2012; Tassinari et al., 2013).

This important role of agriculture in Asia's mega-urban regions is still hardly recognized in policy making as urban governments respond slowly to urban growth in the surrounding rural areas (McGee, 2010). In addition, urban planning which still is based on the urban-rural dichotomy does not consider agricultural land as part of the urban system (Laquian, 2008; McGee, 2010). Therefore, the lack of planning policies in peri-urban regions has led to haphazard urbanization (Goldblum and Wong, 2000; Firman, 2009; Rukmana, 2015). The peri-urban region in this context refers to areas in the outskirts of a designated city boundary where urban and rural characteristics meet each other (Winarso et al., 2015, see also e.g. Ravetz et al., 2013; Zasada et al., 2013 for a discussion of the concept). Megacities as the most important engines of economic growth in Asia still demand more space (Dahiya, 2012), whereas raising social and environmental issues increase a concern to protect green open spaces, including agricultural land. Therefore, the conflict between urban development, food security enhancement, and environmental quality improvement has become a critical issue for the future development of peri-urban regions.

It has been suggested that urban-rural linkages for the reciprocal economic, social and ecological benefits between urban and rural areas should be developed (Douglass, 1998). However, this idea cannot be easily applied in the case of desakota due to its urban-rural continuum where defining mutual flows of services between these two systems is complicated (Lynch, 2005; Gutman 2007). Therefore, a new model is required to develop integrated rural–urban systems that respond to the specific environmental, social, economic, and institutional aspects of peri-urban regions (Allen, 2003; Gutman, 2007), particularly that experiences desakota phenomenon.

Urban agriculture offers a promising concept to addressing some of the challenges of peri-urban regions. It not only refers to management of farmland in the urban and peri-urban areas (Smit et al., 1996) but emphasizes the integration of agriculture into urban socioeconomic and ecological systems (Mougeot, 2000). Urban agriculture uses urban resources (e.g. labor, land, water, infrastructure, etc.); markets produce to urban inhabitants; is influenced by urban policies and plans (e.g. high competition of labor, land, etc.); and affects the urban system (e.g. having an effect on urban poverty, food security, and environmental health) (RUAF, 2010; De Zeeuw et al., 2011).

According to Zasada (2011) developing multifunctionality and connectivity to the urban system is a key to preserve agricultural land in the dynamic peri-urban areas. However, the mechanisms for developing multifunctional farmland and its integration into the land use and economic system of mega-urban regions in Asia are still poorly understood (Malaque III and Yokohari, 2007; Lee et al., 2015). Particularly, there is a lack of understanding of: (1) farming types in peri-urban areas and their particular response to rapid urban expansion; (2) the potential ecological and social benefits derived from these farming types; and (3) effective policies for integrating agriculture into urban development and for enhancing their social and ecological benefits.

This research aims to contribute to closing these knowledge gaps by a study on peri-urban agriculture (PUA) in the Jabodetabek Metropolitan Area (JMA). JMA encompasses Jakarta as the core city and the capital of Indonesia, which is surrounded by municipalities and districts of Bogor, Depok, Tangerang, and Bekasi. JMA has become one of the fastest growing megacities in the world (Cox, 2011; World Bank, 2015), and with a population that reached 28 million in 2010, a region considered the second largest megacity worldwide (Cox, 2011; RIHN, 2014). Particularly, JMA is the region where the initial concept of desakota was developed (McGee, 1991).

Along with rapid urbanization, JMA faces pressing challenges of increasing poverty and food insecurity among its population (Rustiadi et al., 2015). Furthermore, urban expansion has been related to increased incidences of flood and landslides (Rustiadi et al., 2015; Remondi et al., 2016), an intensifying urban heat island (Effendy, 2009; Tokairin et al., 2010), and diminishing provision of ecosystem services including fresh water, biodiversity conservation, and outdoor recreational areas (Vollmer et al., 2016). It is hypothesized in this study that agricultural land which covers a large proportion of the area in peri-urban JMA (Rustiadi et al., 2012a) can make an important contribution to solving these problems if successfully integrated into the urban system.

Research questions that will be addressed in this research refer to the specific response of different urban farming types to urbanization; their economic, social, and environmental functions within the urban system; and how to develop these functions. Therefore, the objectives of this study are:

(1) to investigate the character of urban sprawl and its impacts on the dynamics of PUA,

(2) to analyze the relationships between PUA types and socioeconomic issues (e.g. food security, urban poverty) as well as environmental issues (e.g. flood retention) in urban planning and development,

(3) to assess the potential of PUA contributing to the sustainability of the JMA through multifunctional farming (i.e. farming function beyond food and fiber production), and

(4) to draw conclusions towards development of policies which effectively support multifunctional PUA.

1.2 Structure of the Thesis

The structure of the thesis reflects the research objectives, multiple-methods used in the study, and the results of empirical research as it is shown in Figure 1. Research objective 1 employed land use change analysis, descriptive and multivariate analysis of socioeconomic panel data, and spatial mapping and clustering of farming types. This approach allowed to characterize the dynamics and functions of PUA during rapid urbanization in the JMA (macro level study). The results are presented in Paper I.

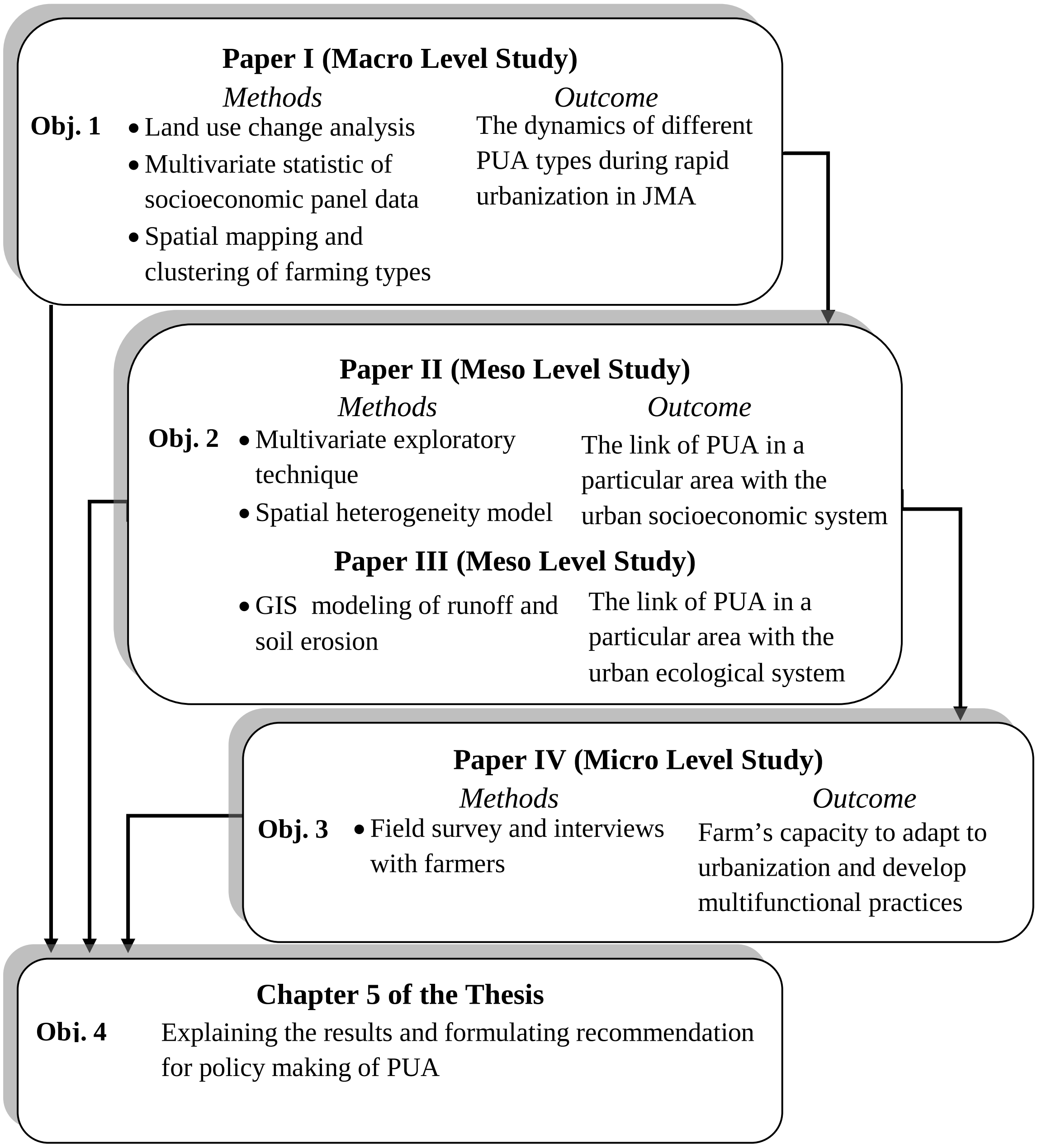

Figure 1. Structure and overview of the dissertation

Two studies were conducted to address objective 2 by exploring the links between PUA with (1) the socioeconomic urban system, and (2) the ecological urban system. The first study used methods of multivariate exploratory techniques and spatial heterogeneity modelling, while the second study used an approach of GIS modelling of runoff and soil erosion. Both studies aimed to identify the roles of different PUA types in a particular area to deal with socioeconomic and environmental issues of JMA such as food security, urban poverty, and flood retention. Conclusions were drawn for developing strategies to manage PUA in different zones of JMA (meso level study), and they are presented in Paper II and III.

A further study was conducted to analyze how PUA with its multiple functions in a particular zone of JMA can be sustained regarding the situation at the farm level. It is related to the research objective 3. A field survey in a catchment area of the Ciliwung stream traversing JMA was done by doing questionnaire based interviews with farmers. Results represent the situation of PUA at the farm level (micro level study) and its potency to adapt to urbanization and practice multifunctional farming. The results are presented in Paper IV.

Chapter 2 of this thesis contains a literature review to provide the theoretical background for this research. Chapter 3 introduces the methodological framework of the research and summarizes the multiple methods which were applied in Paper I to IV. Furthermore, chapter 4 summarizes and synthesizes the results of Paper I to IV regarding the research questions. Chapter 5 discusses the overall results and presents recommendations to develop policies of PUA that can be integrated into urban planning and development. This will answer the research objective 4. Finally, chapter 6 draws conclusions from this research for developing multifunctional PUA to support resilience and sustainability of the JMA, in particular, and Asian megacity, in general.

2. LITERATURE REVIEW

2.1 Urban Sprawl and the Desakota Phenomenon

Urbanization has become one of the most important phenomena of global change as 54% of the world population lived in urban area in 2014, and it will increase to 66% in 2050 (UN, 2014). Africa and Asia are urbanizing faster than other regions (UN, 2014), and particularly in Asia is characterized by the emerging megacities of 10 million or more inhabitants (Blum, 2015; Legget, 2015) where large population size and economic activities are strongly correlated (Swert and Denis, 2015). Physically, megacities are characterized by large urban expansion beyond the urban core to form mega-urban regions that cover cities, towns, villages, and rural areas (McGee, 1991).

The role of Asian megacities as engines of economic growth is emphasized in the scientific discourse on future Asian development (Dahiya, 2012; Swert and Denis, 2015). However, they increasingly face issues of uncontrolled land consumption via urban sprawl, urban transport infrastructure and urban waste management, lacking infrastructure of the inner city, declining green open spaces, increasing pollution and environmental hazard, and rising urban poverty (Singh, 2015). Along with the emerging issues of global climate change, now enhancing urban resilience has become a crucial issue for the future planning of Asian megacities (Singh, 2015; Swert and Denis, 2015).

Urban sprawl is recognized as a common problem of urbanization in Asia (Mookherjee and Hoerauf, 2015). According to Ewing (1994, 1997) urban sprawl refers to the expansion of urban regions into the adjacent rural landscape characterized by low densities, scattered and discontinuous “leapfrog” development, intermingling of different forms of urban and rural land use, and increased use of private vehicles for commuting. This describes inefficiencies of the urban growth where land per capita for urban uses is increasing, but losing large tracts of agricultural and natural land in the urban fringes has resulted in deteriorated environmental health (Meeus and Gulinck, 2008). In Asia, urbanization has led to the conversion of more than 10 km^2 of farmland per day due to population growth of over 45 million a year in the last two decades (Dahiya, 2012). Furthermore, the low density expansion of urban areas puts economic strains on the core city to provide technical and social infrastructures and services (UN Habitat, 2010a).

Compared to cities in other parts of the world, urban sprawl in Asia show a higher pace and scale (Swert and Denis, 2015). Rapid urban expansion is mainly caused by rural-to-urban migration (UNESCAP, 2013) as a consequence of strong economic development which is overly centralized in the cities (Dahiya, 2012; UNESCAP, 2013). Moreover, there is a lack of capacity of planning to control and direct the spatial development of cities. Planning policy in Asian megacities is characterized by a narrow conception of physical planning as infrastructure development while neglecting socioeconomic and ecological dimensions; a strong dichotomy between urban and rural; government fragmentation; and incapability to make detailed plans (Laquian, 2008).

McGee (1991) explained that expanding metropolitan regions often penetrate important agricultural areas inhabited by a dense rural population which leads to a typical feature of peri-urban Asia called desakota. Desakota is characterized by a mixture of agricultural and urban activities as well as formal and informal sectors (Moench and Gyawali, 2008; Swert and Denis, 2015), pluri-activities, and intensity of commuting (Swert and Denis, 2015).

Despite strong pressures from urbanization, fragmented farmland in the peri-urban still survives as can be traced from the historical development of numerous Asian megacities (Yokohari et al., 2000). Even when people start to work as laborers in industry or services sectors, they often continue farming (Yokohari et al., 2000; Moench and Gwayali, 2008). Still, some scholars keep arguing that desakota is a chaotic feature during the process of urbanization that will vanish when the process is complete (Chan, 1994; Dick and Rimmer, 1998; Hudalah and Firman, 2012).

On the other hand, McGee (2010) argued that the desakota region will become a crucial zone to achieve sustainable development because its resource base and proximity to the urban core make this area key for “food security” policies under the threats of energy and food price volatility on the global market. In the future, volatility of the global agricultural market will be likely increasing due to: (1) growing population and income in merging and developing countries, (2) increasing agricultural production for biofuel, (3) agricultural commodity prices which are becoming more correlated with oil price as this influences fuel price, fertilizer price, etc., and (4) global climate change that affect agricultural productivity (FAO et al., 2011). In addition, desakota regions can contribute to alleviating poverty, increasing resilience against environmental hazards and climate change (Pelling and Mustafa, 2010), as well as providing environmental services (Moench and Gyawali, 2008; McGee, 2010).

Therefore, a well-planned combination of rural and urban landscapes has been proposed as a new ecological planning concept for the future Asian megacities (Yokohari et al., 2000). Regarding the concept, farmland in urban fringe areas may provide socioeconomic and ecological services simultaneously (Gutman, 2007; McGee, 2010), thus landscape units with contiguous agriculture should be preserved (Malaque III and Yokohari, 2007). This will affect not only the livelihoods and quality of life of those who live in these areas, but also the sustainability of urban and rural simultaneously (Allen, 2003).

However, managing the desakota region is not an easy task due to its strong dynamics and inherent complexities. Due to the collision of the urban and the rural sphere, desakota regions often face problems of vulnerability, poverty, social conflicts, and environmental degradation (Pelling and Mustafa, 2010; Firman, 2009). For instance, the needs of urban dwellers for water and green open spaces for private use often create social, economic, and ecological conflicts with rural communities who see these as common pool resources (Pelling and Mustafa, 2010). These conflicts can trigger vulnerability and poverty as many rural inhabitants lose their access to land and natural resources during urbanization. Furthermore, conversion and fragmentation of agricultural and natural areas have led to increasing environmental degradation.

This complexity leads to lacking policies to manage desakota regions in mega-urban Asia (McGee, 2010). Policies for strengthening urban-rural linkages failed as urban and rural areas in desakota regions have been intermingled, even they closely interact to form a distinctive type of area (Lynch, 2005; Tassinari et al., 2013).

Instead, urban and rural entities in desakota regions should be able to build social, economic, and ecological integration through promoting community activities, practicing participatory development planning, etc. (Douglass, 2013). It will bring multiple benefits, including social cohesion, economic resilience, and environmental health, not only for peri-urban dwellers, but also for all mega-urban inhabitants (Douglass, 2013; Gutman, 2007). A specific approach to manage this region is needed (Allen, 2003; Rustiadi et al., 2015) as peri-urban is not just a zone of urban-rural transition, but it is a new type of multifunctional territory (Ravetz et al., 2013). Strategic policy to manage desakota regions as a hybrid of urban-rural systems should be considered in sustainable urban development trajectories (McGee, 2010; Rustiadi et al., 2015).

2.2 Urban and Peri-urban Agriculture

The concept of urban agriculture has been adopted widely since it was first endorsed by UNDP and FAO in 1996 (Mougeot, 2000). Urban agriculture has been defined as an activity that encompasses the production, processing, and marketing of agricultural commodities, including crops and livestock, by using land, water, labor, and other resources in urban and peri-urban area (UNDP, 1996; Zezza and Tasciotti, 2010). It was estimated that 800 million people were engaged in urban agriculture worldwide to support one-third of global consumption (UNDP, 1996). Although the accuracy of this number is questioned, the important role of urban agriculture in developing countries for food provision cannot be neglected (Zezza and Tasciotti, 2010).

Instead of defining urban agriculture simply as farming in the urban and peri-urban areas, Mougeot (2000) emphasized that urban agriculture is characterized by its embeddedness in and its interaction with urban economic and ecological systems. In this sense, urban agriculture uses urban labor and urban resources (land, water, etc.); has a direct link with urban consumers; becomes part of the urban food system; benefits from developed urban infrastructure; competes with other urban functions in using land, water, labor, etc.; delivers regulation services (micro climate, soil, and water management); and is affected by urban planning and policies (Mougeot, 2000; RUAF, 2010). As urban agriculture mutually interacts with other urban elements, likely it has a potential to strengthen urban management policies (Mougeot, 2000).

According to the Food and Agriculture Organization (FAO, 1999), urban agriculture can provide food, generate employment, recycle urban wastes, create green belts, and enhance urban resilience to climate change. As Asian megacities face the problems of urban sprawl, environmental degradation, food insecurity, and poverty (Dahiya, 2012; Singh, 2015; Rustiadi et al., 2015), managing farmland in the peri-urban is likely even more important. Zasada (2011) argued that the success of PUA management will depend on linking agricultural policy with urban agendas such as climate change and adaptation, public health and food quality, leisure, and community services.

Particularly, PUA is expected to support people's livelihoods (De Bon et al., 2010; De Zeeuw et al., 2011), enhance food security and alleviate poverty (Zezza and Tasciotti, 2010; Lee et al., 2015; Tsuchiya et al., 2015), and provide various agro-ecosystem services (Yang et al., 2010; Aubry et al., 2012; Lee et al., 2015). Furthermore, results from the interpretation of satellite imagery of 120 cities worldwide from 1990 to 2000 showed that the doubling of value added per hectare of farmland results in a 26 % decline of urban expansion (Angel et al., 2005).

However, preserving PUA during rapid urbanization also received a lot of criticism. The effectiveness of PUA to alleviate poverty and generate employment is questioned as it is not a major economic activity in urbanized areas (Zezza and Tasciotti, 2010), its capacity to support food security is questioned as the production continually declines due to farmland conversion (FAO 1999; Vagneron, 2007), and some studies revealed that farming activities harmed the urban environment, especially through leaching of fertilizers and chemical compound to the water drainage system (Vagneron, 2007; Khai et al., 2007; Hussain and Hanisch, 2014) and bad odor from livestocks (Moon, 2015). It has also been suggested that regulation of micro-climate by PUA may be lower than of nature protected areas (Koomen et al., 2008). Furthermore, PUA also produces greenhouse gas emission such as methane from irrigated paddy rice as a dominant agricultural type in Asia (Van Groenigen et al., 2012).

Additionally, there is a lack of rigorous study about the benefits of PUA. Therefore, policies for supporting urban agriculture are rarely supported by reliable data as much of the evidence is still qualitative (Zezza and Tasciotti, 2010). The literature on urban agriculture is also more driven by advocacy rather than rigorous analysis (Ellis and Sumberg, 1998; Webb, 2011). Furthermore, De Zeeuw et al. (2011) noted that most of PUA, especially in developing countries, is illegal or informal. Therefore, it is not regulated by government and there is a lack of regular statistical data (Padgham et al., 2015).

Regarding this situation, there is a need for more studies on which, where, for what reasons, and how the PUA should be preserved or developed (Aubry et al., 2012). Without convincing evidence, allocating public budget to support PUA is hard to be arranged (Zezza and Tasciotti, 2010). In addition, more evidence on the measurable benefits of PUA is required to focus policies and programs for its promotion (Broch et al., 2013).

Therefore, the functions of PUA need to be thoroughly assessed, especially in peri-urban Asia where farmland frequently covers a large proportion of land use (Rustiadi et al., 2012a; Lee et al., 2015). Particularly, a better understanding is needed on the capacity of different PUA types to adapt to urbanization (Zezza and Tasciotti, 2010) and to provide specific functions in different areas of peri-urban regions (Aubry et al., 2012). Developing multifunctionality and linking of PUA with the urban system can enhance farmland preservation (Zasada, 2011) as well as support a new ecological planning concept for managing desakota regions suggested by Yokohari et al. (2000).

2.3 The Development of Multifunctional Peri-urban Agriculture

Multifunctional agriculture has been proposed as a strategy to increase the capacity of PUA farmers dealing with multiple urban challenges, e.g. competition for land, water, and labor, while realizing opportunities, e.g. arising from increasing food demand, and close proximity to urban consumers, etc. (De Bon et al., 2010; Zasada, 2011). The concept is different from pluriactivity of farms where farmers and their family conduct other gainful activities through agricultural and non-agricultural employment, or diversify farming products and services as strategies to survive (Blad, 2014). Multifunctional agriculture has a broader scope as farming is expected to support food security; enhance the environment and mitigate environmental hazards; produce goods and services for the economic system, and sustain the viability of rural communities, including those who live in the peri-urban, by supporting their livelihoods and culture (FAO, 2000).

Therefore, the development of multifunctional agriculture is not only determined by farming capacity to provide products and services, but it is also affected by societal demands and the political-institutional frameworks (Renting et al., 2009; Van der Ploeg et al., 2009). Farmers and the community might have preferences for different agricultural functions (Howley et al., 2014). Thus, multifunctionality can be different in particular social, economic, and geographical settings (Renting et al., 2009; Van der Ploeg et al., 2009).

Moon (2015) argued that multifunctionality depends on natural resources endowment, ecological conditions, farm policies, and culture/history that determine economic development and agricultural competitiveness. Economic development will lead to a rising demand for agricultural functions to deliver public goods such as environmental health, cultural values, and amenity/aesthetics. It is relevant for Asian urbanization which is characterized by increasing numbers of middle and high class communities who benefit from urban economic growth (UN Habitat and UNESCAP, 2015).

On the other hand, higher agricultural productivity is expected to support food security, poverty alleviation, and community livelihoods. It is also relevant for Asian cities as these areas become home to the world largest urban slum population and the largest concentration of urban poverty (UN Habitat and UNESCAP, 2015). Rural-to-urban migrants contribute greatly to urban population growth and most of them work in the informal sectors excluded from wider benefits of economic growth (UNESCAP, 2013). Due to lack of jobs and income, they face a problem of food insecurity as food in the cities should be purchased.

Therefore, PUA in Asia should play two major roles simultaneously. Firstly, to serve growing urban demands for a better living environment, and secondly, to enhance farm productivity of producing food especially for underprivileged urban dwellers, maintaining farmers' livelihoods, and alleviating poverty (De Bon et al., 2010; Zezza and Tasciotti, 2010; McGee, 2010; De Zeeuw et al., 2011). Still, combining production and non-production functions in agricultural policy is a big challenge (Moon, 2015).

One of the challenges is that every type of farming has a different capacity to develop multifunctionality depending on its particular commodities, farmland sizes, farming practices, intensity of land use, and location (Zasada, 2011; Aubry et al., 2012). Therefore, the situation at the farm level needs to be understood (Aubry et al., 2012; Wilson, 2009). Simulation studies of cost-benefit ratios of farming showed that developing services beyond food and fiber production (e.g. social, cultural, and ecological functions of farmland) are capable to increase the profitability and sustainability of farming business in peri-urban areas (Vagneron, 2007; Prändl-Zika, 2008; Aubry et al., 2012). However, further strategies are required to transform rural-traditional farming in the peri-urban into multifunctional agriculture practices (Aubry et al., 2012).

Economic market incentives, regulatory instruments and land use planning, and decision making processes of different actors have been suggested to support multifunctional agriculture (Renting et al., 2009). Economic market incentives are developed based on valuation of non-market services of farmland (e.g. amenity, aesthetics, environmental improvement, culture, viability of rural or peri-urban communities, etc.). Land use planning policy is arranged to protect and maintain socioeconomic and ecological services of agricultural landscape. Furthermore, public participation in policy making for multifunctional agriculture will raise people's awareness to support farmers in developing multifunctional farming.

Wilson (2007, 2008) described the importance of farmers' decision making towards weak or strong multifunctionality. Weak multifunctionality merely puts focus on food and fiber production, whereas strong multifunctionality is characterized by high environmental sustainability; strong embeddedness in the local and regional economy (e.g. generating income and employment, enhancing the viability of rural livelihoods); short food supply chains; low farming intensity and productivity (e.g. lower use of agrochemical inputs); weak integration into the global capitalist market; a high degree of diversification; and a high degree of the rural population who understand agriculture as an activity that goes beyond food and fiber production. Furthermore, Wilson (2007, 2008) argued that the transition of a farming towards weak or strong multifunctionality is influenced by farming types (e.g. full time or part time, large scale or small scale, for hobby or economics purposes); and farming ownership types (e.g. owner-occupied properties, farms in multi-member ownership, tenant farmers). Increasing farm size, ownership, and economic turnover are regarded as factors that can stimulate the transition of farming towards strong multifunctional agriculture.

Obviously, developing multifunctionality should consider both the policies at the city level and farmers' decision making at the farm level which have cumulative effects throughout the landscape (Aubry et al., 2012; Padgham et al., 2015). Wilson (2009) has pointed out that understanding of actions and views of the farmers as the decision makers in the agricultural space is important to develop sustainable multifunctional agriculture. Furthermore, recognizing farm level characteristics is a key to identify the opportunities and constraints of farming activities to participate in programs of sustainable urban development (Mawois et al., 2011).

Developing multifunctional PUA will be a great challenge regarding the situation of farming practices in peri-urban Asia. Agricultural land conversion and fragmentation continually occur in the peri-urban regions and result in smaller patches of farmland and lower farming revenues (Rahman and Rahman, 2008; Lee et al., 2015). Declining soil and water quality lessen agricultural productivity (Huang et al., 2006; Vagneron, 2007; Materechera, 2009; Vazhacharickal et al., 2013). Insecure land property rights and lack of policy support threaten the continuity of farming (Siregar, 2006; Bersaglio and Kepe, 2014; Rehman et al., 2013; Aubry et al., 2012; Indraprahasta, 2013; Robineau, 2015). Despite increasing demand for food and agro-ecosystem services, all these factors will lead to the loss of motivation to continue farming.

2.4 PUA and Urban Planning Policy

Despite the argument of PUA benefits, preserving farmland in urban and peri-urban areas is still complicated (Paül and McKenzie, 2103). Multi-criteria GIS models based on multi-stakeholders assessment have been developed to delineate protected agricultural zones in the peri-urban (Thapa and Murayama, 2008; Tassinari et al., 2013, Russo et al., 2014). However, lack of understanding of the links between PUA and the socioeconomic and ecological dynamics of urban development will make this approach ineffective (Aubry et al., 2012; Paül and McKenzie, 2103).

For this purpose, the present and future roles of agriculture in urban development need to be assessed (Aubry et al., 2012). Therefore, benefits, beneficiaries, and the costs to generate the benefits in a particular farmland should be known to assist policy makers in urban and land use planning (Vollmer et al., 2016). As each type of the benefits or disbenefits of PUA has an influence on different ranges of areas (Wilson, 2009), a multi-level approach that encompasses regional, local, and farm level is needed. The analysis will support policies for PUA which are able to develop public benefits at the landscape level and enhance farming sustainability at the farm level (Aubry et al., 2012).

At the city level, the roles of PUA to support food supply chains and agro-ecosystem services are emphasized (Wilson 2009; Lovell, 2010). Some cities consider farmland as productive green spaces that not only provide food, but also offer spaces for recreation and improving visual quality (Lovell, 2010), contribute to flood mitigation and adaptation (Morris et al., 2010) as well as the management of urban waste water (Lovell, 2010; Russo et al., 2014).

At the local level, the roles of PUA to alleviate poverty and support rural livelihood are emphasized. Especially in developing countries, the role of PUA to produce food, income, and employment for the poor is required (Zezza and Tasciotti, 2010). Furthermore, the role of PUA to deal with local environmental issues is also important as farming practices influence water and soil quality (Huang et al., 2006; Khai et al., 2007).

At the farm-level, farmers' decision making affects the sustainability of the farming business (Wilson 2009, Lovell 2010). Farming in the peri-urban should have a capacity to survive as an economic activity (Aubry et al., 2012). Therefore, farmers' decision making in adapting to urban situation should lead to development of multifunctional practices that could generate higher revenues from activities beyond food and fiber production (Zasada 2011, Aubry et al., 2012).

A multi-level approach is also required to lessen spatial inconsistencies between policy, farming structure, and agro-ecological process (Lefebvre et al., 2015;

Whittingham et al., 2007), thus policies of PUA can be applied effectively. Besides, adopting a multilevel approach is important to develop integrated policies of PUA that helps to overcome the urban-rural dichotomy and fragmented governance in Asian megacities (Laquian, 2008; McGee, 2010).

2.5 Knowledge Gaps for Integrated PUA Planning and Management

From the literature review, it can be concluded that there is a considerable gap between the potential role of PUA for sustainable development of the desakota region and urban planning policy. The gap exists on different levels of the planning hierarchy. At the macro/city level, there is a debate about the future roles of PUA within the growing urban system as an engine of economic growth. Lack of empirical evidence about the dynamics of PUA within the socioeconomic and ecological dynamics of the urban system leads to limited knowledge about the actual roles of PUA. Consequently, public and urban government are not sufficiently concerned about the impact of farmland loss in the urban fringes.

At the meso/local level, lack of information about specific socioeconomic and ecological functions of PUA in the urban system hampers the development of PUA planning policy. Developing urban and peri-urban agricultural zones based on multi-stakeholders' assessment offers an alternative solution. However, links of PUA with other urban elements such as settlement, infrastructure, industrial, commercial areas, etc. remain unclear. Therefore, it is difficult to develop synergies between agricultural policy and other urban agendas such as economic development, infrastructure building, climate change adaptation, environmental hazard mitigation, etc. An improved knowledge is required regarding different characteristics of farming types in the peri-urban such as their capacity to adapt to the urban system, their spatial distribution, and socioeconomic and environmental benefits that they can deliver for improving quality of life in urban and peri-urban areas.

At the farm level, developing farming activities beyond food and fiber production (multifunctional agriculture) is challenging. It is the most crucial issue as multifunctionality is a key to successful management of PUA. Decision making by farmers has been regarded as an important factor for adopting multifunctional practices. However, lack of knowledge about farming activities in the peri-urban region and farmers' adaptation to urbanization hinders development of strategies to influence farmers' decision making for adopting multifunctional practices.

In conclusion, a multilevel approach is proposed as an analytical framework for studying PUA, especially related to the situation in Asian megacities. Figure 2 provides an overview of multilevel relationships as an analytical framework of this doctoral thesis.

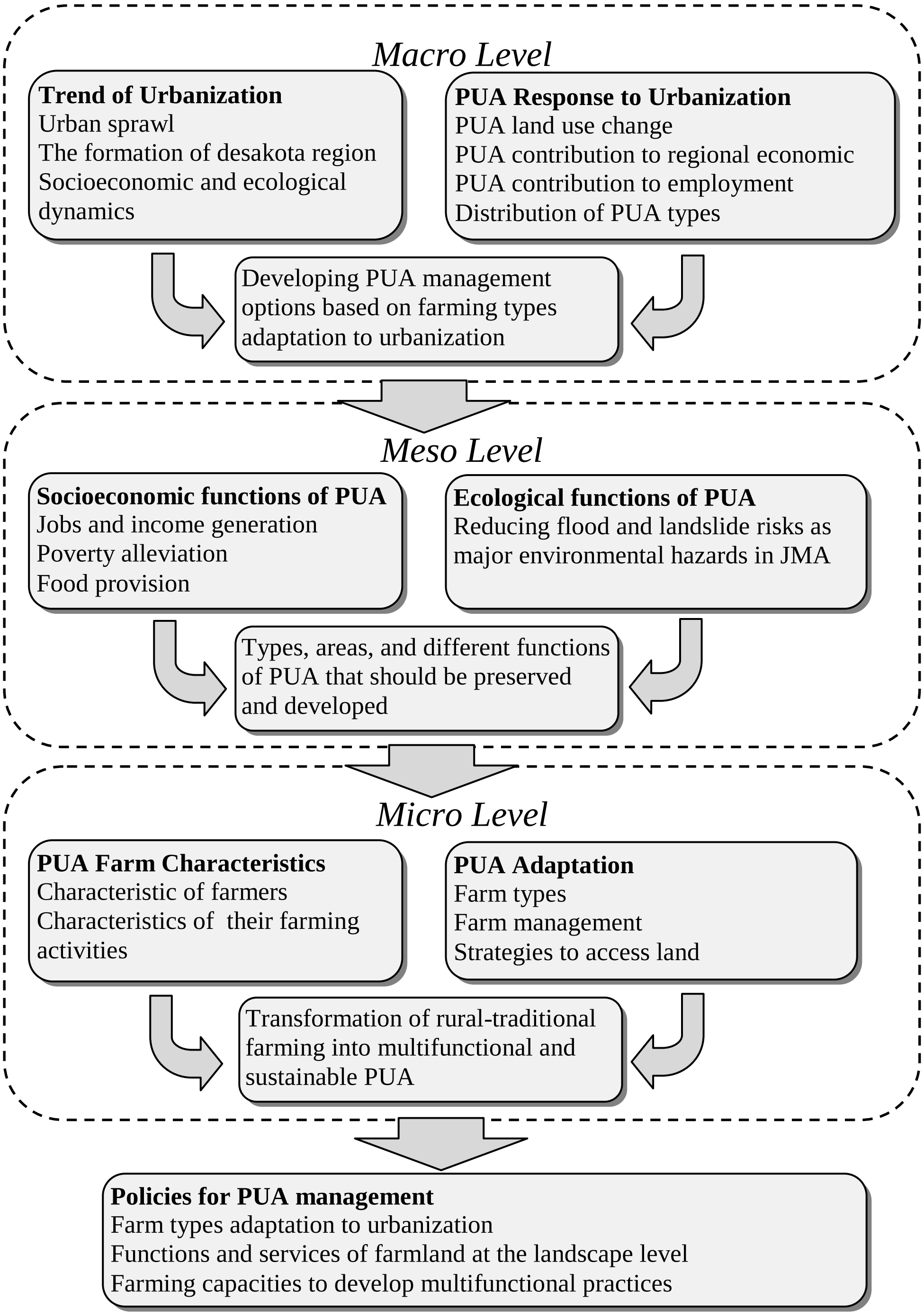

Figure 2 Analytical framework of the doctoral study

3. MATERIAL AND METHODS

3.1 Study Area

The research was conducted in Jabodetabek Metropolitan Area (JMA). Jabodetabek stands for Jakarta, the capital city of Indonesia and the urban core of JMA, which is surrounded by municipalities and districts of Bogor, Depok, Tangerang, and Bekasi. In total, this area encompasses 10 municipalities and 3 districts which are part of three provinces, namely Jakarta, West Java, and Banten (see Figure 3).

JMA covers a total area of 6,256 km2 with a population 27.96 million in 2010. They are distributed over 183 sub-districts and over 1,495 villages in 2011. The northern part is comprised of the alluvial zone, while the southern part is comprised of mountainous area. There are three major watersheds in JMA where their streams cross the area from south to north, namely Kali Bekasi, Ciliwung, and Cisadane. The catchment area of these watersheds is located in the south of JMA as part of the Salak and Gede-Pangrango mountain ranges. Kali Bekasi, Ciliwung, and Cisadane streams mainly flows to the downstream Bekasi, Jakarta, and Tangerang respectively.

JMA has experienced rapid urban expansion since the early 1980’s. Urban land use has expanded towards densely populated agricultural land in the surroundings of Jakarta and it has been followed by increasing flood and landslide incidences (Rustiadi et al., 2012a).

This research concentrates on agricultural land in the peri-urban zone of JMA. In this study, the peri-urban zone of JMA is defined as an area in the outskirt Jakarta (around Jakarta region boundaries), plus a peripheral area of Jakarta that covers 5 municipalities and 3 districts of Bogor, Depok, Tangerang, and Bekasi (Hudalah and Firman, 2012). All of these areas were considered for studies in Paper I which analyzed PUA roles in JMA (macro scale) and Paper II that analyzed socioeconomic roles of PUA in different areas of peri-urban JMA (meso scale). Particularly for Paper III, the study focused on the catchment areas of three major watersheds (Kali Bekasi, Ciliwung, and Cisadane) as critical areas to lessen flood and landslide risks in JMA. While, Paper IV focused only on the Ciliwung catchment area for studying farmers’ behavior (micro-level).

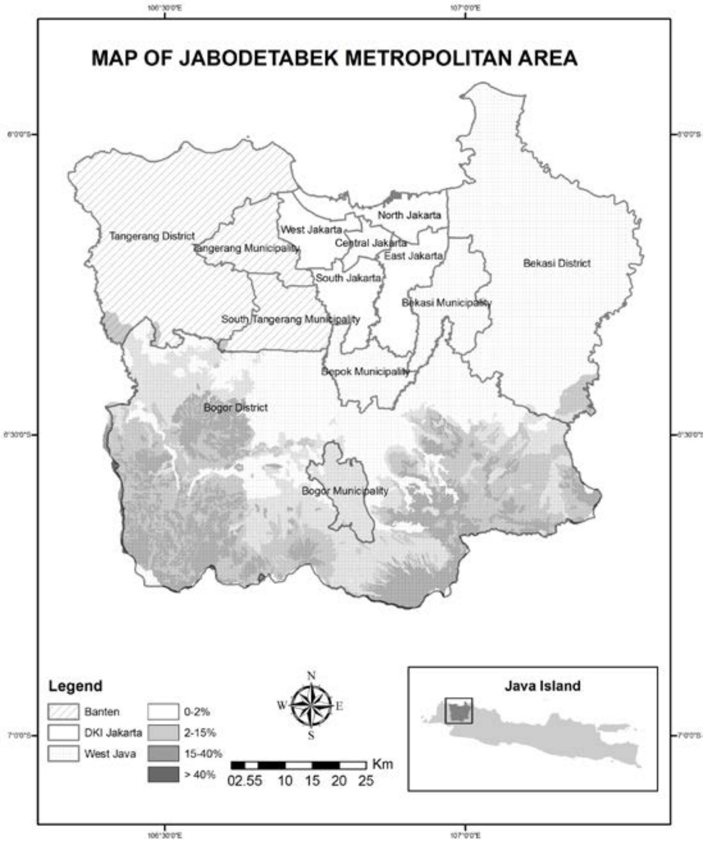

Figure 3 Map of Jabodetabek Metropolitan Area

3.2 Methods

The methodology of the study was developed based on the analytical framework in Chapter 2. Different methods were applied regarding specific PUA management issues at different levels of the planning hierarchy from the city/macro level, the local/meso level to the farm/micro level.

3.2.1 Analysis of PUA Dynamics during Rapid Urbanization (Macro Level)

This study was presented in Paper I. The study aimed to examine how rapid urban growth in JMA affected PUA, to define social-economic relevance of PUA in the midst of rapid urban growth, and to analyze the distribution of PUA types and how they adapt to urban growth. Each of the methods can be explained as follows.

Land Use Change Analysis

A series of land use maps were used to identify urban expansion and the changes of farmland. Land use maps were developed from time series images data of

Landsat for the years 1972 (MSS), 1983 (TM), 1995 (TM), 2005 (TM), and 2012 (ETM+). These data were selected based on their clarity to portray the whole area of JMA. The MSS and TM data were re-sampled to a 15 x 15 m pixel to allow multi-temporal comparison with ETM+ data, which was enhanced by using a 15-m panchromatic band.

Afterwards, 443 points were surveyed in the field for defining the spectral signature of each class and selecting a combination of spectral bands to provide maximum separability of each class. Thus, by applying a supervised classification, which means that the satellite image is being trained using representative points from different classes collected in the field, the Landsat image 2012 was classified into 12 classes of land uses divided into PUA and non PUA land use category (Table 1).

Table 1 Land use class characteristic

Land Use	Description
Fishpond*	Covered by water
Dryland agriculture*	Non-irrigated farmland cultivated with annual plants in horticulture or other food crops such as corn, sweet potato, etc.
Mixed garden*	Non-irrigated farmland cultivated with a mix of annual and perennial plants
Plantation*	Non-irrigated farmland cultivated with perennial plants
Paddy field*	Rainfed paddy field only cultivated in the rainy season
Inundated paddy field*	Irrigated paddy field cultivated throughout the year
Water body	Covered by water (lake, river)
Forest	Natural area with woody plants
Bush	Abandoned land covered by bush
Scrub	An area covered by small plants including grass
Open space	Bare land
Built up-area	Settlements, buildings, etc.

** = PUA land use*

The accuracy of this classification was assessed by setting up 75 independent ground control points. Particularly for classification of the older images, information of former land uses was collected from field interviews and the older JMA land use maps from Rustiadi et al. (2012a). Then, different series of land use maps were overlaid to identify the land use changes, especially the gains and losses of built-up area (urban growth) and PUA land use types from 1972 to 2012.

The pattern of urban growth was analyzed based on the change of development density. It was measured by identifying population density within the built-up zone in 1993, 2003, and 2008, based on the Village Potency Data (PODES), a database of physical and socioeconomic features of a village, published by the Central

Statistic Agency (BPS). Furthermore, land fragmentation due to urban growth was defined by using an overlapping neighborhood statistic function in ArcGIS to calculate the numbers of neighborhoods that cover single land use and mixed land use over time (1972, 1983, 1995, 2005, 2012). The size of a neighborhood was set to 50 m × 50 m (0.25 ha) as the average size of farmland patches in the peri-urban JMA is 0.1-0.2 ha (BPS, 2013).

The gain and losses of PUA land use types were also calculated to identify type specific responses of PUA to urban growth in JMA. In addition, the effect of PUA land use changes on non-PUA land use changes were also identified.

Analysis of socioeconomic panel data

The GDP sectoral data by municipality/district of JMA from 1993 to 2010 established by BPS was used to analyze the contribution of the agricultural sector in the peri-urban zone (Bogor, Depok, Tangerang, and Bekasi) to regional economics. The share of the agricultural sector in total GDP of the peri-urban region was calculated. Further analysis was then performed to analyze the relationship between the agricultural sector in the peri-urban and other economic sectors in JMA. Within this analysis, the GDP data were divided into the GDP of urban (Jakarta) and the GDP of peri-urban. Then, Principal Component Analysis (PCA) was employed to extract new independent factors of composite areas (urban and peri-urban) and sectors (9 sectors of GDP). The score of new factors was plotted on a graph to analyze the dynamic contribution of PUA within the development of other sectors in JMA from 1993 to 2010.

The role of PUA in the social system of JMA was analyzed based on time series data on: (1) farmer household numbers consisting of those who work on their own farm and landless farmer household, and (2) number of villages where 50% of the population have an income from the agricultural sector (on and off-farm). The data were obtained from PODES in 1993, 1996, 2000, 2003, 2006, 2008, and 2011.

Spatial mapping and clustering of agricultural types

This analysis was based on data on the number of farmers belonging to different farming types in each village of JMA. The data were derived from

Population Census Data 2010 (Sensus Penduduk 2010) established by BPS which describe the distribution of farming types better than land use types data. There were six farming types consisting of paddy & food crops, horticulture, plantation, fisheries, livestock, and forestry & others. Further classification was done by using data on agricultural production of each municipality/district 2012 from BPS, completed by field observation on agricultural land use which was conducted in 2013.

The spatial distribution of farming types over villages was analyzed based on proximity between the types and other factors that represent accessibility (distance to arterial roads, local roads, population number), and infrastructure or environmental supports (the presence of rivers, lake, and irrigation). Depending on the type of data, PCA was done to analyze the spatial association between different farming types. Pearson's correlation coefficient was employed to define the relationship between farming types and accessibility. Furthermore, Pearson's chi square was used to analyze the correlation between farming types and environmental support.

3.2.2 Analysis Of PUA Roles in the Urban Socioeconomic System (Meso Level)

This study was written in Paper II. The study aimed to analyze the different roles of PUA in different areas of peri-urban JMA based on its relationship with (1) urban economic activities, (2) urban poverty and informality, and (3) food security. The approaches used in this study can be explained as follows.

Correlation analysis between PUA and Urban Economic Activities

The correlation analysis was based on the dynamics of PUA, on the one hand, and the dynamics of urban economic activities, on the other. The dynamics of PUA were represented by changes of the number of farmers in each village of JMA from 2006 to 2011, while the dynamics of urban economic activities were represented by changes of the number of households, hotels, villas, restaurants, permanent and non-permanent traditional markets, small scale industries, mini-markets, food stalls, and stalls in each village of JMA from 2006 to 2011. The increasing number was coded by "1", while the remainder were coded by "0". The data were obtained from PODES 2006 and 2011. The years were chosen as the results of macro-level study showed that the GDP of PUA in these periods had constantly increased (cf. Figure 5b, Paper I).

As the data were binary, a Correspondence Analysis (CA) was used to measure the correlation between variables. CA is an exploratory technique to analyze simple two ways and multiple-way tables containing measures of correspondence between rows and columns within a crosstabulation of frequency (Statsoft, 2007). The proximity between variables on the CA graph reflects the degree of correlation between variables.

Regression analysis between PUA and Urban Poverty, Informality, and Food Security

Regression analysis is a common approach to define the relationship between variables. However, as it was assumed that the link of PUA with socioeconomic issues varies between different areas, Geographically Weighted Regression (GWR) was employed. GWR is a method which allows to identify the varying relationship between variables across the different parts of a study area. It contains local parameter estimates as disaggregation of the ordinary/global regression (Fotheringham et al., 2002). This study used unit area of sub-districts.

Two GWR models were developed to define the relationship between (1) PUA and urban poverty and informality, and (2) PUA and food security. In the first model, the ratio of farmers on total workers was used as the dependent variable, while explanatory variables consisted of: (1) ratio of poor people on total population; (2) ratio of almost poor people on total population; (3) ratio of self employed on total workers; (4) ratio of free-worker on total workers, and (5) ratio of non paid worker on total workers. The first two explanatory variables represent poverty, while the remaining variables represent informality. The data obtained from Population Census 2010 published by BPS, and particularly for poverty, the number of poor and almost poor people in 2011 was obtained from the National Task Force for Poverty Alleviation (Tim Nasional Percepatan Penanggulangan Kemiskinan-TNP2K).

Poor people were defined as inhabitants that have income below the poverty line (25 USD/capita/month according to BPS, 2011), while almost poor people were defined as inhabitants that have income slightly above the poverty line. Both were classified as a vulnerable group to poverty (TNP2K, 2012). On the other hand, self-employed were defined as people who have their own business or offer particular skills such as tailors, carpenters, builders, barbers, etc.; free-workers were defined as people who have non-permanent job; and non-paid workers were defined as people who work in the family business without salary.

In the second model, some of the variables were based on household data from the National Social-Economic Survey 2010 published by BPS (Susenas 2010). The household data were standardized, therefore they had a similar size of four family members. The average amount of money spent by a household to buy staple food per month was used as a dependent variable. It represented food affordability as the most important indicator of food security policy (Indonesian Government, 2002). It was assumed that the staple foods were consumed in a relatively similar quantity per household, including rice, fish, meat, eggs, milk, vegetables, fruits, cooking oil, drinks (e.g. coffee, tea, etc.), and spices. Furthermore, the explanatory variables consisted of: (1) the average total expenses of a household per month, (2) the ratio of average food expenses on average total expenses of a household per month, and (3) the ratio of farmers on total workers. The first explanatory variable represents the total income of a household, whereas the second represents a household capacity to deal with food price fluctuation as the amount of staple food consumption per household is relatively stable.

The local parameter estimates of sub-district which were significant based on *t*-test with $\alpha = 0.05$ of the two models were mapped. Afterwards, the PUA types which were presented in the significant sub-district were identified. Based on Paper I results, overall, PUA types in JMA consisted of: (1) lowland paddy & food crops, (2) upland paddy & food crops, (3) lowland horticulture, (4) upland horticulture, (5) plantation, (6) inland aquaculture, (7) marine fisheries & coastal aquaculture, (8) livestock, (9) forestry, and (10) hunting and others.

3.2.3 Analysis of PUA Roles in the Urban Environmental System (Meso Level)

This study was written in Paper III. The study area was the upstream areas of JMA consisting the catchment area of Kali Bekasi, Ciliwung, and Cisadane watersheds (see Figure 4). The study aimed to identify the changes of types of PUA and their distribution in the study area, to analyze the effect of PUA dynamics on runoff and soil erosion that influence flooding as a major environmental hazard in

JMA, and to define a zoning of PUA where its management should reduce runoff and soil erosion. The approaches used in this study can be described as follows.

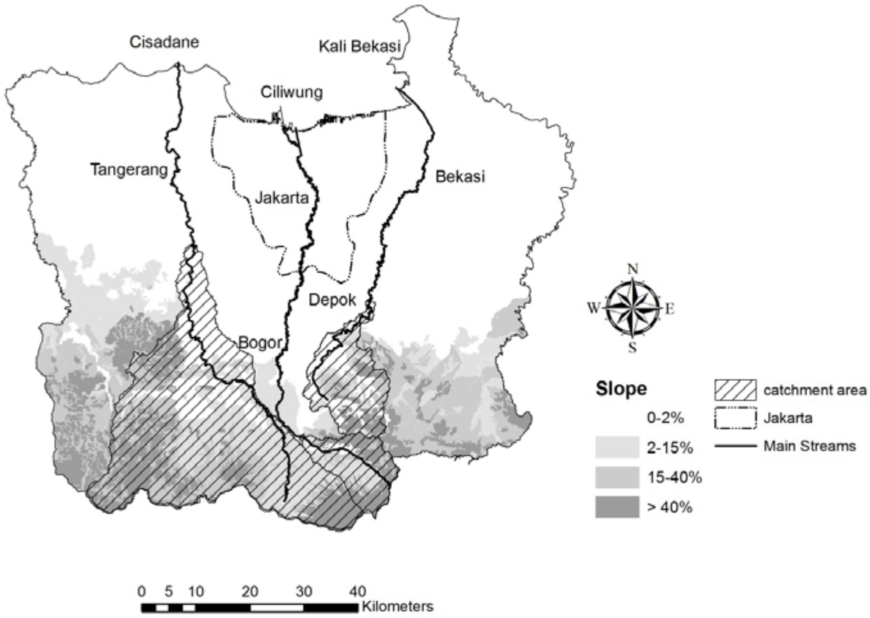

Figure 4 Map of the catchment areas of Kali Bekasi, Ciliwung, and Cisadane in JMA

Analysis of PUA dynamics

PUA land use changes in the study area were identified based on JMA land use maps 1983 and 2012 as already resulted by Paper I. Instead of 1972, the year 1983 was chosen in this analysis as urban growth beyond the urban core (Jakarta) in JMA began in the 1980's (cf. Paper I). Gains and losses of each PUA land use category were identified, and its relation with gains and losses of non-PUA land uses were also assessed (see Table 1).

Measuring the effect of PUA dynamics on runoff

A Peak Flow Model developed by Vis et al. (2012a) was employed to measure the effect of land use change (incl. PUA land) on surface runoff. Factors that influence runoff include rainfall, slope, soil, shape of the catchment area, and land use. The model uses the technique of a spatially distributed hydrograph (SDUH) to delineate areas in the catchment regarding their influence on the peak flow at the outlet of the catchment.

Excess rainfall in each raster cell and the quantity and travel time of surface water flow from each raster cell to the outlet were calculated to form a hydrograph[1] by using a raster GIS function of ArcGIS Spatial Analyst. The contribution from raster cells to the hydrograph at various stages was also drawn into an isochrones map[2]. The model uses an assumption of one hour rainfall with the intensity calculated from the annual rainfall data. This assumption was used as the model focusses on assessing the impact of land use change on runoff.

The data in the model include raster maps of annual rainfall isohyets, topography, stream networks, delineation of the catchment area, and land use with the resolution of 30 m^2. Particularly for land use data, land use maps 1983 and 2012 were used. The other input maps were obtained from Vis et al. (2012a). Every land use types has different capacities to retain runoff based on parameters derived from US Soil Conservation Services (SCS) that have been adjusted to the prevailing land use type in Indonesia (Vis et al., 2012a).

The output of the model consisted of (1) change of the runoff hydrograph from 1983 to 2012 due to land use change (incl. PUA land change), and (2) an isochrones map 2012 showing the zone that contributes most to the formation of peak discharge at the outlet. Then, PUA types in the zone were identified to define their effect on runoff.

Measuring the effect of PUA dynamics on soil erosion

The impact of PUA land use change on soil erosion were assessed by a Java Erosion Model developed by Vis et al. (2012b). The model was based on the USLE (Universal Soil Loss Equation) equation as follows.

$$A = R \times K \times L \times S \times C \times P$$

Note:

A	: annual soil loss per unit area	R	: rainfall erosivity factor
K	: soil erodibility factor	L	: the slope length factor
S	: the slope gradient factor	C	: cropping/management factor
P	: the erosion-control practice factor		

[1] a graph showing the relationship between water flow and time at a specific point in a river.

[2] a map contains lines connecting points at which runoff arrives at the same time at the outlet.

The data in the model include the 1:250,000 soil map of Java of Lembaga Penelitian Tanah (1966) consisting 55 soil types; the 1:1,000,000 of rainfall erosivity map of Java of Bols (1978); and DEM/Slope from SRTM 2000 (30 m^2 of resolution) to obtain the R, K, L, and S factors as physical parameters which are relatively stable. Furthermore, the CP factor matrix was defined based on land use, management level, and slope class. The land use class is shown in Table 1. The slope class was divided into 4 classes consisted of 0-2% (low), 2-15% (moderate), 15-40% (high), >40% (very high). The management level of each land use type follows the research of Hammer (1981) that assessed prevailing farming management in Java includes:

- Bad management: where agricultural management practices are limited and mechanical management practices are restricted to very simple measures like strip cropping
- Actual management: reflects the actual situation in 1980 where some farms used mulching and fertilizer and mechanical management practices were applied in low or moderate ways (e.g. traditional terraces).
- Good management: farmers apply surface mulching, fertilizing, intercropping, and crop diversification, and mechanical management practices concentrate on terracing, either outward sloping terraces or bench terraces.

By introducing land use 1983 and 2012 to the model, the impact of land use change on soil erosion was assessed. For land use 1983, the management level was assumed similar to the actual management in the 1980's. While for land use 2012, the management level followed scenarios of good and bad practice of management as the information about the actual management was unavailable and collecting data through field survey was hampered by cost and time constraint of the study.

Zoning analysis of PUA land management to reduce runoff and soil erosion

An isochrones map 2012 from a Peak Flow Model shows a critical zone for the management of runoff, while a critical zone to mitigate soil erosion was defined by omitting the management factor (C and P) from the USLE equation, resulting in a model called the Bare-Soil Model. This model was used to define areas at risk of erosion (soil erosion > 500 tons/ha/year) and areas that should be reforested (>30% of slope) to avoid soil degradation upstream and sedimentation problems downstream (Vis et al., 2012b).

Both of the maps were overlaid to define zones that influence runoff and soil erosion. This led to 5 zones consisted of: (1) a non-critical zone to runoff and soil erosion, (2) a critical zone to runoff, (3) a critical zone to soil erosion, (4) a critical zone to runoff and soil erosion, and (5) a reforestation zone. Then, PUA types in each zone were identified to formulate policy recommendations for PUA management in each zone.

3.2.4 Analysis of Farming to Develop Multifunctional PUA (Micro Level)

This study was presented in Paper IV. The study aimed to analyze farmers' adaptation to the urban situation, to evaluate whether this adaptation will promote multifunctional agriculture, and to define factors that can enhance the development of multifunctional agriculture. Particular emphasis was placed on (1) response to food market opportunities and urban land pressure, (2) capacity to run the farm business, (3) motivation to continue farming, and (4) access to land as the most competitive resource in the peri-urban area. In order to collect data, interviews with farmers in the Ciliwung catchment as a case study area were arranged. Methods to collect and analyze the data are explained as follows.

Sampling and Farm Survey

Questionnaire based interviews with 101 farmers were carried out. Farmers were selected by a stratified sampling. The stratification was based on their farming location considering their effect on runoff and soil erosion in the Ciliwung catchment. PUA in the upper zone is prone to soil erosion, while PUA in the central zone is prone to runoff and soil erosion. PUA in the lower zone is more suitable for agricultural activities. Furthermore, the selection of sample location also considered the distribution of agricultural land use in the Ciliwung catchment area (see Figure 5).

The questionnaire was designed to characterize the farmers and their farming activities and to define their capacity to develop multifunctional PUA. The character of farmers was represented by age, education, place of origin, agricultural working time, and capital, while the character of farming activities was represented by commodity, farm size, land ownership, and economic turnover. Furthermore, the multifunctional PUA benefits were explored, including PUA potential to alleviate poverty, generate income and employment, enhance food security, reduce runoff and soil erosion, and enhance outdoor recreation for which the area is well known in JMA (Vollmer et al., 2016). In-depth interviews were also conducted to get further information about the reasons behind farmers' decision making in the farming business.

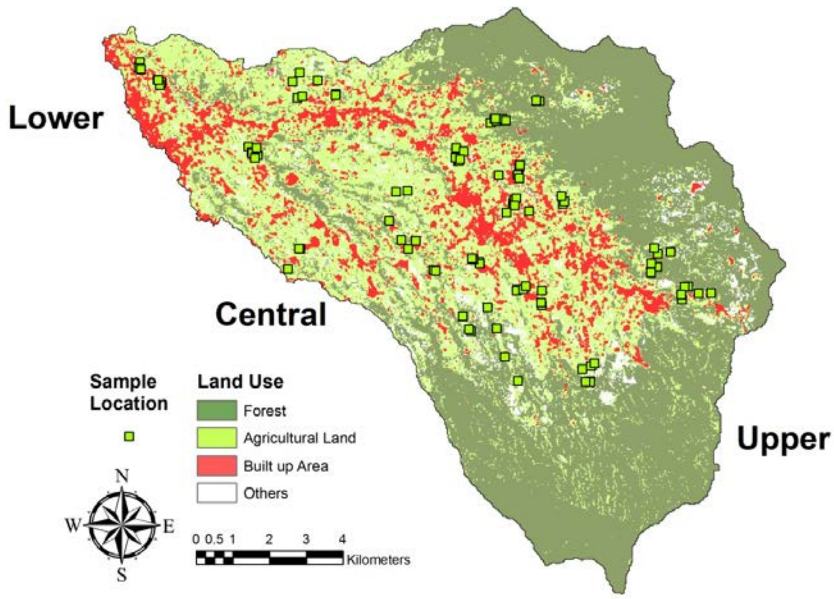

Figure 5 Sample location of the interview

Statistical Data Analysis

Data of farmers and farming characteristics, as well as their contribution to multiple benefits of agriculture were analyzed based on descriptive statistical analysis. Particularly, a cost-benefit ratio (CBR) was calculated to assess economic viability of farming. This calculation was based on one cropping period instead of a year as commodities and cropping pattern in the Ciliwung catchment depicts high variability, and cropping seasons are changing every year depending on the fluctuation of commodity prices in the market.

Furthermore, a Correspondence Analysis (CA) was employed to analyze the relationship between farmers and farming characteristics and their multifunctional benefits. As mentioned before, CA is a technique to measure the association between variables based on frequency data. The purpose was to identify factors that influence the capability of farmers to adapt to urbanization and apply multifunctional practices. Knowing these factors was considered as a key for policy making to push the transformation of rural-traditional farming towards multifunctional PUA.

4. RESULTS

This chapter presents the results of Papers I to IV. The first part focuses on analysis of PUA dynamics, its socioeconomic relevance, and the changing distribution of PUA types in adaptation to urban growth (city/macro level study). The second part explores the potential of PUA to address major challenges of urban development, including socioeconomic such as poverty, informality, food security, and environmental such as runoff and soil erosion (local/meso level study). The third part studies the factors influencing multifunctionality of PUA at the farm level (micro level study) to maintain farming sustainability and support PUA functions at the meso and macro level. Finally, table 2 at the end of the section gives an overview of the research papers' key findings.

4.1 Rapid Urbanization in JMA and Its Impact on PUA (Paper I)

Characteristic of Urbanization in JMA

Serial maps of the development of built-up area from 1972 to 2012 (cf. Figure 2, Paper 1) showed that urbanization in JMA has expanded beyond Jakarta as the urban core since the early of 1980's. Particularly in 1990's, urban expansion in all directions indicated that the policy to direct urban growth towards east and west of Jakarta in order to protect water catchment areas in the south had failed (Suselo, 2006). Due to the worst flooding in JMA in 2007, protecting green open spaces in the south has been reinforced through a new law of spatial planning. Consequently, there has been again urban growth towards the east and west of Jakarta in 2012.

Strong urban expansion in JMA was followed by decreasing population density within built-up areas (cf. Figure 3, Paper I). Large-scale developments in the form of new towns and real estates have fuelled land consumption in the peri-urban JMA since the 1990's (Winarso et al., 2015). Furthermore, this development has led to the phenomenon of fragmented urban sprawl as the mixture of built-up and non-built up land use types increased from 1972 to 2012 (cf. Table 1, Paper 1).

PUA land use change during urbanization

Urban land use (built-up area) increased in JMA from 9,373 ha (1.4%) in 1972 to 223,953 ha (32.9%) in 2012, where 83.1% of the urban growth came from agricultural land. Furthermore, the increasing interspersal of built-up and non built up areas has lead to farmland fragmentation that reduce output and efficiency of farming activities, especially paddy rice (Rahman and Rahman, 2008).

Interestingly, the losses of agricultural land were lower than the urban land take. The overall percentage of agricultural land only decreased less than 10%, from 61.1% in 1972 to 52.45% in 2012. Dryland agriculture and paddy fields, which represent labor intensive small holder agriculture, experienced stronger losses and gains than other PUA types (cf. Figure 4, Paper 1). This finding indicates that most of the converted farmland was replaced by creating new agricultural land in remoter parts of JMA at the expense of forests. Consequently, the percentage of forested land decreased from 34.4% in 1972 to 10.1% in 2012, where 74.8% of the converted forest changed to agriculture.

Socioeconomic relevance of PUA

The contribution of the agricultural sector to the GDP of peri-urban JMA continually decreased from 1993 to 2010, but the slope of the curve declined after the economic crisis in 1997 and 2007 (cf. Figure 5a, Paper I). In absolute terms, the GDP of the agricultural sectors even increased after the economic crisis in 1997 and 2007 (cf. Figure 5b, Paper I). Furthermore, the growth of GDP of the agricultural sector kept pace with other sectors in peri-urban and urban JMA after the crisis (cf. Figure 6, Paper I).

In conjunction with the persistence of agricultural land and the strengthening of the economic role of PUA after the crisis, the number of PUA households increased from 1996 to 2011 (cf. Figure 7a, Paper 1) although the overall percentage of farmers in the peri-urban population decreased (cf. Figure 7b, Paper 1). However, the proportion of landless farmers increased, especially from 2003 to 2011, thus it can be argued that they will become vulnerable to any future economic crisis. Still in 2011, there were 537 villages in the peri-urban area (43.5% of the total number of villages) where more than 50% of the population made a livelihood from on-farm and off-farm activities (e.g. trade and transport of agricultural products; sales of fertilizers, seeds, pesticides, and agricultural equipment; processing agricultural products, etc.).

PUA types and their adaptation to urbanization

Based on BPS data enhanced with field observations, a distinction was made between PUA types based on commodity types, land resource characteristics, and supporting infrastructures. Overall, 10 PUA types were identified in JMA consisting of: (1) lowland paddy & food crops, (2) upland paddy & food crops, (3) lowland horticulture, (4) upland horticulture, (5) plantation, (6) inland aquaculture, (7) marine fisheries & coastal aquaculture, (8) livestock, (9) forestry, and (10) hunting and others.

Spatial mapping and clustering of the PUA types showed specific responses to urbanization. First, PUA that can adapt to and benefit from urbanization were distinguished such as lowland horticulture and inland aquaculture. These farming types benefit from the proximity to the arterial roads and populated areas (cf. Table 2, Paper 1). Lowland horticulture usually uses small patches of land, the vegetables can be frequently harvested, and the proximity to urban markets can provide quick income. Inland aquaculture has a similar character, but it only exists near the city with a sufficient water supply.

Second, PUA that is vulnerable to urbanization and is pushed to the places further from urbanized areas were recognized such as lowland and upland paddy & food crops, upland horticulture, and livestock. They persisted in areas with low population density, far from arterial roads, but still close to local roads. Furthermore, their presences also depend on the existence of rivers, lake, and irrigation (cf. Table 2, Paper 1). Paddy rice and upland horticulture move away from settlements to get a larger area and generate more profit. Whereas livestock cannot be located near settlements because of bad odor and animal waste.

Third, there are PUA types that remain in place such as plantation, forestry, and marine fisheries & coastal aquaculture. They were located far from arterial roads, in less populated areas (except marine fisheries & coastal aquaculture as fishing villages in Indonesia normally have a dense population), and significantly correlated with the presence of rivers or irrigation (cf. Table 2, Paper 1). Some plantations such as oil palm, rubber, and tea still exist in JMA, but the pressure of urbanization is increasing. Similarly, marine fisheries & coastal aquaculture is threatened by pollution and waste that decrease the water quality of the sea north of Jakarta.

4.2. PUA and Its Relationship with the Urban Socioeconomic System (Paper II)

The relationship between PUA and urban economic activities

Villages in JMA where the number of farmers was growing from 2006 to 2011 were mostly distributed sparsely in the peri-urban area and mixed up with urban activities (cf. Figure 2a, Paper II). This growth of farmers was related to increasing low-middle class residential areas and small-middle scale urban economic activities (households, mini-markets, food stalls, stalls, etc.), but not to tourism activities (hotels, villas, restaurants) and traditional market facilities (i.e. a market where people trade daily based on negotiable price) (cf. Figure 2b, Paper II). Apparently, due to the small size of farming and small quantity of products, PUA farmers prefer to sell their harvest to the consumers in the nearby residential areas, instead of supporting hotels, restaurants, and traditional markets that need a big quantity and continuity of supply.

The relationship between PUA and urban poverty and informality

Increasing overall poverty of the population led to an increasing proportion of farmers in the southeast of JMA, but a decreasing proportion of farmers in the north of JMA (cf. Figure 3, Paper II). Seemingly, low capital farming in the southeast such as upland paddy & food crops (cf. Figure 4, Paper II) has eased poor people to farm for getting small income or food subsistence. PUA in the north was dominated by capital intensive farming supported by better infrastructures (e.g. irrigation, transportation, electricity, etc.) such as lowland/irrigated paddy & food crops, lowland horticulture, marine & coastal aquaculture, and livestock (cf. Figure 4, Paper II). They can offer a higher income but also need higher input to reach optimal productivity. Consequently, poor farmers that lack capital cannot continue farming.

Furthermore, an increase in informal workers was correlated with an increasing proportion of farmers in the peri-urban (cf. Figure 5, Paper II), which again emphasizes the strong relationship between PUA and small-middle scale economic activities that are mostly informal. Three types of informal works, i.e. self-employed, free workers, and non-paid workers were able to support the persistence of lowland

and upland paddy & food crops farms as the dominant agricultural types in the peri-urban JMA (cf. Figure 6, Paper II). Both PUA types are labor intensive agricultural activities that produce low income.

The relationship between PUA and food security

An increasing number of farmers made a significant contribution to reduce household expenses for the staple food of the entire population. However, this trend could only be observed in PUA land in surrounding Jakarta, east, and northeast of JMA (cf. Figure 7, Paper II). The proximity to urban markets enhances the capacity of PUA in this area to supply food for urban inhabitants. The PUA in this area mainly consisted of lowland and upland paddy & food crops, lowland horticulture, marine & coastal aquaculture, and livestock (cf. Figure 8, Paper II) that produce staple food such as rice, fish, meat, eggs, milk, vegetables, fruits, and spices.

4.3. PUA and Its Relationship with Environmental Issues (Paper III)

Jakarta, the capital of Indonesia, has suffered from an increasing number of big floodings in 1996, 2002, 2007, and 2013 mainly due to massive land use change (Farid et al., 2010; Rustiadi et al., 2015). The quality of three major watersheds in JMA namely Kali Bekasi, Ciliwung, and Cisadane is critical, especially the capability of their catchment areas to retain and infiltrate water and thus reduce flood risks (BPDAS Citarum-Ciliwung, 2011; BBWS Ciliwung-Cisadane, 2012). Moreover, high intensity of runoff has caused increasing incidences of landslides mainly in the three mentioned catchment areas (Rustiadi et al., 2015).

As agricultural land covered 53% of land use in 2012, the role of PUA in flood management becomes crucial. Particularly, when rapid urban expansion has pushed agricultural land from the urbanized areas downstream to the distant areas upstream. Therefore, the roles of PUA in influencing the quality of three important catchment areas in JMA should be assessed as the effect of agriculture on water-related landscapes functions varies depending on the type, distribution, and management of farmland.

PUA land use changes in each catchment

PUA land in the three catchment areas expanded from 1983 to 2012 and became the dominant land use type (cf. Figure 4, Paper III). Farmland increased from 50% to 56%, 14% to 35%, and 30% to 55% of the total area of Kali Bekasi, Ciliwung, and Cisadane catchments respectively. Dryland agriculture and mixed gardens became dominant agricultural land use types in all catchments, while inundated paddy fields in sizeable proportion were only found in Kali Bekasi and Cisadane. Farmland expansion contributed to 78%, 74%, and 82% of total forest loss in the upstream area of Kali Bekasi, Ciliwung, and Cisadane.

The Effect of PUA land use change on runoff

The results of a Peak Flow Model showed that the hydrograph between 1983 and 2012 at the outlet of the three catchments experienced an increasing peak flow, total runoff, while the time to reach the peak flow became shorter due to the land use change (cf. Figure 5, Paper III). The peak flow increased by 18.5%, 15.2%, and 27.7%, while the total runoff increased by 11.8%, 12.2%, and 10.5% in Kali Bekasi, Ciliwung, and Cisadane respectively. Furthermore, the time to reach the peak flow became one hour less in all three catchments: from 11 to 10 hours in Kali Bekasi, from 6 to 5 hours in Ciliwung, and from 12 to 11 hours in Cisadane. Consequently, this situation has increased flood risks in the downstream areas of JMA.

Furthermore, the isochrones map 2012 showed that the zone that contributes most to the formation of the peak flow in the three catchments was dominated by farmland. In Kali Bekasi, agricultural land in the zone was 70%, mainly consisting of dryland agriculture (48%), mixed gardens (11%), and inundated paddy fields (9%). In Ciliwung, agricultural land in the zone reached 40%, mainly consisting of dryland agriculture (32%), mixed gardens (7%), and inundated paddy fields (1%). In Cisadane, agricultural land in the zone covered 71%, mainly consisting of dryland agriculture (42%), inundated paddy fields (12%), and mixed gardens (10%). Dryland agriculture and mixed gardens have emerged as a dominant PUA land use type, and both have a lower capacity to retain runoff compared to forest.

The Effect of PUA land use change on soil erosion

Expanding farmland from 1983 to 2012 had different effects on soil erosion. In Kali Bekasi, introducing good farm management would lead to a decrease the amount of soil erosion by 30% despite the expansion of agricultural land in 2012. In contrast, expanding agricultural land in the Ciliwung catchment intensified soil erosion by 120% under good farm management and 674% under bad farm management. In Cisadane soil erosion would increase by 43% under good farm management, but the increase would reach 450% under bad farm management. Results indicate that good farm management can counterbalance the increasing soil erosion due to farmland expansion, especially in Kali Bekasi and Cisadane catchment.

Zoning of PUA for land management to reduce runoff and soil erosion

Zoning analysis showed the distribution of PUA land use within 5 zones (see Chapter 3). In all three catchments, the results of the zoning approach showed that most of the farmland was located in the critical zones to runoff and soil erosion (zone 2, 3, and 4) (cf. Figure 7, Paper III). In Kali Bekasi, 74% of agricultural land were predominantly located in the critical zones. It mainly consisted of dryland agriculture, mixed gardens, and inundated paddy fields. In Ciliwung, 81% of agricultural land were located in the critical zones with dryland agriculture and mixed garden as major types. Cisadane had a lower proportion of agricultural land in the critical zones that reached 58%, while 33% was sited in the non-critical zone to runoff and soil erosion (zone 1). Agricultural land in both zones was dominated by dryland agriculture, mixed gardens, and inundated paddy fields, respectively. In all three catchments, only a small proportion of farmland was in the reforestation zone (zone 5) consisting 9% in Kali Bekasi, 10% in Ciliwung, and 9% in Cisadane.

4.4. Developing Multifunctional PUA at the Farm Level (Paper IV)

Multifuncionality of PUA at the landscape level needs to be supported by farmers' decision making to apply multifunctional practices on their farmland. Therefore, Wilson's (2007, 2008) concept of multifunctional transition at the farm-level was adopted to analyze the respective potentials and limitations of different farming types in the Ciliwung catchment area to develop strong multifunctionality.

The analysis focuses on the current capacity of farmers to provide multifunctional farming benefits, and farm characteristics that support strong multifunctionality.

Farmers and Their Farming Characteristics

Among 101 interviewees, only 13% of farmers had an education above primary education. Most of them (77%) were still in the working age regarding BPS criteria (between 15-64 years old). 25% of farmers came from outside of JMA. Full-time farmers were dominant, either they had secondary non-agriculture jobs (33%) or not (40%). Most of the farmers were active in horticulture (53%), while some others were growing paddy rice (43%). Only a small number of farmers cultivated other food crops (i.e. secondary food crop commodities after paddy rice) mainly corn and sweet potato. Most of the farmers (87%) did not own land, thus they had an access to land by a production sharing agreement, renting the land, working as a property guard (i.e. property includes houses, gardens, and land), giving a loan to the land owner who want to mortgage their land, and illegally opening land for farming at the edge of forests.

Horticulture covered the majority of the surveyed farmland (cf. Figure 2, Paper IV). Horticultural farmers practiced multiple cropping with various commodities such as carrots, tomato, spring onion, chili, cabbage, etc. They also applied a high cropping intensity as the land was always cultivated throughout the year. Most of horticultural farms occupied comparatively larger plots of land in the upper area of the Ciliwung catchment, far from settlements, and near the forest. On the other hand, paddy rice farmers could only harvest two times in a year as they did not have capital to farm three times, furthermore, the land needs to lie fallow to restore its fertility. Moreover, paddy rice farms and other food crops were cultivated on the smaller land in the central and lower areas of the Ciliwung catchments near settlements.

Multifunctional Farming Benefits

Income and employment generated by the different farm types can be seen in Table 2, Paper IV. Horticultural farms offered a higher income and job opportunities as they had larger farm sizes, more intensive input, higher output, and generated more profit (higher value of CBR). In addition, more people were employed as horticultural farms needed an intensive treatment within a short cropping period (e.g. planting, watering, fertilization, spraying, harvesting, etc.). On the other hand, paddy rice farms generated a lower income and less employment. Most of paddy rice farms had small parcels of fields, used less input, and produced lower outputs and profit (low value of CBR). Paddy farmers also required work forces only during the planting and harvesting periods. Other food crops resembled horticultural farms, but this result may not be a representative as the number of samples was small (N=4) and included two large scale farms supported by rich investors from Jakarta.

The contribution of farming to enhance food security can be seen in Figure 3, Paper IV. Most of horticultural farmers sold their produce at the regional market in JMA. Other food crops were mostly marketed locally to serve visitors who were interested to buy roasted corn and boiled sweet potato as well-known products from Puncak, the most favorite tourism area in the Ciliwung catchment. Paddy farmers mostly used their produce for their own consumption.

Environmental benefits of farming were not really obvious. Horticulture as a major farming type applied chemical fertilizers, pesticides, and herbicides to a larger degree (the average cost was 398 USD/ha/season). It was similar to farming of other food crops as some of them were large scale and capital intensive farming (the average cost was 311 USD/ha/season). Only paddy rice farms used less fertilizers, pesticides, and herbicides (the average cost was 103 USD/ha/season). In addition, organic farming as well as soil and water conservation practices were rarely observed, particularly in horticultural farms. According to interviewees, organic farming was rarely practiced because of knowledge barriers, labor intensity, and limited size of the market. Moreover, most of horticultural farmers did not apply soil and water conservation principles such as mulching, regular plant rotation, temporarily leaving land fallow, utilization of organic matter, or cultivation on terraced land. Some of them even cultivated land intensively on steep slopes not following the contour lines. Only paddy rice farms applied some of these conservation practices, especially the utilization of organic matter and leaving a land fallow for one cropping season in a year. As a result, land productivity of horticulture and other food crops was mostly reported to decrease, whereas land productivity of paddy rice farms mostly remained stable in the last 5 years (cf. Figure 4b, Paper IV). Still, the majority of farmland in the Ciliwung catchment could attract urban tourists to visit and involve in farming activities, or to harvest and to buy agricultural products directly from the farms.

Farm Characteristics that Support Strong Multifunctionality of Farming

Analysis of the relationships between farm characteristic and multifunctional farming benefits showed interesting findings. Horticultural farming was associated with full-time, young, and capital intensive farmers. Subsequently, horticulture could generate employment and income. Furthermore, horticulture was also associated with a higher CBR, and was related to the regional food supply. In contrast, paddy rice farming was associated with part-time, older farmers who had little capital (cf. Figure 7, Paper IV). It was associated with a lower CBR and was related to domestic needs (cf. Figure 8, Paper IV). Even though this farming type did not support employment and income generation, it was important for food supply of the poor people.

Related to the type of land access, horticulture was closely associated with rented land, guarded land, and illegal land, whereas paddy rice farming was associated with production sharing (cf. Figure 9a, Paper IV). Farming on illegal land and production sharing did not have a close association with the issue of farmland conversion (i.e. the possibility of farmers to continue farming on the current land for the next five years). Rather, the probability to continue farming varied depending on the landowner's decision for production-sharing land, or the degree of law enforcement for illegal land. On the other hand, the land access type "guarded land" was related to a lower risk of farmland conversion, whereas rented land was related to a higher risk of farmland conversion (cf. Figure 9b, Paper IV). A lower risk of farmland conversion led to stable productivity, whereas a higher risk of farmland conversion led to declining productivity (cf. Figure 9c, Paper IV). This describes how the type of land access influences the sustainability of farming as well as environmental quality of the farmed land.

Overall, the results of the analysis indicate that farm characteristic regarding farmers' individual capacity (working time, age, working capital), their farming motives (profit oriented or subsistence), and land tenure relate to the choices of farming types. Subsequently, each farming type has a different capacity to generate income and employment, enhance food security, and affect the environment.

Table 2 Overview of the main findings

Rapid urbanization in JMA and its impact on PUA
• Continuation of urban sprawl caused farmland conversion and fragmentation in the peri-urban region. • Farmland loss was lower than urban land take as it shifted to further areas and penetrated the forest. • PUA contribution to support food security and regional economy was enhanced at the time of economic crisis in 1998 and 2007. • PUA still supports the livelihood of many peri-urban dwellers through on-farm and off-farm activities. • Lowland horticulture and inland aquaculture benefit from the nearby urban markets, whereas lowland and upland paddy & food crops, upland horticulture, and livestock were pushed away from the urbanized areas.
The relationship of PUA and urban development issues in JMA
• PUA had a close economic link with low and middle class residential areas and small-medium scale urban economic activities. • Increasing numbers of poor people were followed by increasing numbers of farmers in the southeast and decreasing numbers of farmer in the north of JMA. • PUA had a close relationship with informal economic activities in the peri-urban region. • PUA had a capability to support food security policy only in the surroundings of Jakarta, east, and northeast of JMA. • Expansion of PUA in the catchment areas led to increased runoff and soil erosion. • Dryland horticulture and mixed garden dominated land use in the critical zone to runoff and soil erosion and both have a lower capacity to retain runoff and infiltrate water than the forest. • Most of PUA land still can be preserved as long as soil and water conservation principles are applied to reduce runoff and soil erosion. • Only a minor proportion of PUA land in the catchment areas should be reforested.
Developing multifunctional PUA at the farm level
• Horticulture emerged as large-scale farming further from the settlements that benefit from growing urban markets, whereas paddy fields showed subsistence farming near settlements that suffer from land conversion and fragmentation. • Both farming types showed differences in the provision of and trade-offs between income generation, employment, commodity distribution, and environmental services. • Farmers' decision making for multifunctional practices was determined by their individual capacity, intrinsic motives, and land tenure situation.

5. DISCUSSION

This chapter discusses the characteristics and potential roles of peri-urban agriculture (PUA) to deal with the prevailing socioeconomic and environmental issues in JMA from the macro/city level to micro/farm level. Particular emphasis will be given to drawing conclusions towards development of policies for the preservation and management of PUA. Moreover, the relevance of the results from this research to the wider context of Asian megacities will be further explored.

5.1. Roles of PUA in JMA (Macro Level)

JMA has experienced rapid urban expansion in the last four decades. Urban expansion has occurred beyond the urban core towards all directions without being controlled. Although the government has started to curb urban expansion in the water catchment areas in the south since a big flood event in 2007 (Bappeda Kabupaten Bogor, 2014), still, the magnitude of urbanization in JMA is high. Urban growth in JMA in the coming years is predicted to follow the global trend of post-suburbia where industrial estates and new urban centers expand into the peri-urban regions (Hudalah and Firman, 2012; Winarso et al., 2015). Furthermore, JMA has been established as a national strategic region (Kawasan Strategis Nasional/KSN) whereby its development will be promoted to accelerate economic growth (Indonesian Government, 2008).

As shown in this research, urban growth was followed by declining population density and increasing land use fragmentation. Consequently, agricultural activities in the peri-urban have undergone decreasing output and efficiency (see also Rahman and Rahman, 2008) due to farmland conversion and fragmentation.

Yet, interestingly, PUA keeps persisting during the four decades of rapid urbanization process in JMA. While large areas of farmland near the city were lost due to urban expansion (Firman, 2000; cf. Paper I), farmers continue farming on land in remote areas which has resulted in the conversion of forest land. Consequently, environmental risk in JMA, particularly flooding and landslides, have been increasing (Rustiadi et al., 2012a; Rustiadi et al., 2012b).

On the other hand, the enhanced role of PUA in the regional economy can be shown from the contribution of PUA to the GDP that increased after the economic crisis in 1997 and 2007. Volatility of the global agricultural market caused rising prices of imported food, thus increasing demand for local agricultural products. Although the contribution of PUA to peri-urban GDP continually declined, this trend slowed down in 1997 and 2007. Furthermore, the GDP of PUA kept pace with other sectors in peri-urban and urban JMA after the crisis. These findings indicate that to some extent PUA has become connected to the urban economic system.

Strengthening the agricultural sector after the crisis has given opportunities to the farmers to survive and, surprisingly, even to increase in numbers. Even farmers from outside of JMA have entered the horticulture business (Siregar, 2006). Moreover, many peri-urban dwellers were still involved in agricultural business as the majority of the population in almost 50% of the villages are still working in the agricultural sector (i.e. on-farm and off-farm). However, the increase of agricultural jobs was followed by a growing number of landless farmers. An explanation is that farmers who lost their farms due to urbanization had a lack of skills to get a job in urban sectors, thus they have kept working in the farming business as farm workers (Arai, 2011).

PUA shows type-specific responses to urbanization. PUA types that only require small patches of land, where the crops can be harvested quickly, and which produce multiple commodities with a high price, are capable to survive in the midst of urban expansion. They even benefit from the proximity to the urban market. For instance, lowland horticulture farms are mostly located on the vacant land near the city such as the river banks, roadsides, railways sides, and public or private lands which are not developed yet (Purnomohadi, 2001; Siregar, 2006). The farmers usually build a small wooden house on the farmland, work intensively (Siregar, 2006), and quickly move when the land will be developed for another use. Another example is inland aquaculture. It produces many kinds of ornamental fish and fish for consumption that should be transported alive or in fresh condition to the market. However, as inland aquaculture needs a sufficient water supply, it has mostly developed in areas having many lakes and rivers, particularly in the southwest of

Bogor district which are well known as a production center of freshwater fish since the 1980's (PSP3, 2010).

In contrast, other PUA types have been pushed outward by urbanization due to different reasons. Paddy rice and food crops generates low benefit, is highly influenced by the growing season (i.e. rainy and dry seasons), and produces single commodities. Therefore, it is not capable to compete with urban economic activities. Upland horticulture, even though it produces multiple commodities with higher prices, has moved to larger land in remote areas to benefit from the increasing demand of urban food markets. Livestock has also moved away from the expanding settlements because of bad odor and animal waste.

The results of this study thus provide a better understanding of the interaction between urbanization and the PUA. On the one hand, PUA provides jobs and income for the farmers and peri-urban dwellers as well as enhances urban food security at the time of economic crisis. On the other hand, the shifting of PUA land has threatened forest land and increased the environmental risk in JMA.

This situation confirms an argument by Yokohari et al. (2000), and De Zeeuw et al. (2011) that PUA actually is a permanent feature of urban land use, although its location in the urban region may shift over time. Furthermore, PUA will undergo a transformation during urbanization, and to some extent, contributes to enhancing sustainability and resiliency of urban regions (Mougeot, 2000; De Zeeuw et al., 2011). Therefore, results of this study provide compelling evidence that neglecting the dynamics of PUA will not only threaten the livelihoods of numerous peri-urban dwellers, but also the resilience of JMA to higher food price and natural hazards.

Policies for PUA should be adjusted to the size, distribution, and dynamics of agricultural types as a response to urbanization. For instance, horticulture and inland aquaculture are potentially developed in the small and fragmented land near urban settlements. On the other hand, paddy fields and food crops, upland horticulture, and livestock can be maintained by designing agricultural zones as suggested by Paül and McKenzie (2013) to increase their efficiency and sustainability as well as to control their shifting to the forest land. Additionally, the integration of PUA to the urban system needs to be enhanced through development of multifunctional PUA to provide food, alleviate poverty, generate income, and improve environmental health.

As this study was based on multiple spatial and temporal databases of the overall JMA region, it did not explore PUA functions in different areas of JMA. Moreover, this study did not analyze the situation at the farm level, thus the mechanism behind the dynamics of PUA were still unknown. Therefore, further study at the local level (meso) and the farm level (micro) were needed to enhance the integration of PUA into urban planning policy.

5.2. Multiple Roles of PUA in Different Areas of JMA (Meso Level)

PUA Roles in the Urban Socio Economic System

The PUA has a close relationship with low-middle class residential areas and small-middle scale economic activities in the peri-urban. Regardless of real estate development, low cost housing has been widely developed in the peri-urban JMA due to the government program to provide homes for low-income inhabitants (Jakarta Globe, 2013). Although this program contributes to the conversion of more agricultural land, it also stimulates increasing various demands of the residents for local products, especially food. Therefore, small-middle scale economic activities such as food street vendors, food peddlers, food stalls, stalls, small food and beverage industries, etc. have increased the market for PUA.

On the other hand, as PUA is dominated by small scale farming, the farmers tend to farm near settlements for better access to middlemen, petty traders, and consumers. Farmers prefer to sell bigger harvests on-site to a middleman, whereas small harvests and crops that are harvested several times in one cropping season are directly sold to the consumers or petty traders. A shorter market chain is important for small farmers as it can reduce transportation cost, generate cash quickly, and lessen the risk of marketing (e.g. price falls, unsold products, decaying products, etc.).

Therefore, it can be understood that PUA farmers do not prefer to sell their produce directly to the traditional market (see also Tsuchiya et al. 2015). Besides, PUA also has limited access to traditional markets that are dominated by products from the wholesale markets of Jakarta (see Eliyani, 2010). Furthermore, the expansion of hotels, villas, and restaurants do not support PUA as there is no business cooperation with farmers, although visitors are coming to enjoy agricultural landscapes and rural amenity in the peri-urban. To some extent, social segregation between urban and rural community in the peri-urban JMA (Winarso et al., 2015) is a barrier for the cooperation between farmers and tourism business.

The strong relationship between PUA and small-middle scale economic activities that are mostly informal also emphasizes the strong connection between PUA and informal jobs. The results of the study show that the increase of informal jobs in the peri-urban JMA has promoted PUA. Poor farmers are able to work, either as self-employed or free workers such as small traders, porter, gardener, pedicab drivers, construction laborers, etc. by using the spare time between harvest and the planting season (see also Webster 2002; Rochaeni and Lakollo, 2005). This additional income is not only important for living, but also for keeping farming activities as a food source for daily consumption. Furthermore, increasing numbers of free workers and non-paid workers from the farmer’s family can provide labor for farming.

Still, the poverty issue in PUA is crucial. In the southeast of JMA, increasing poverty leads to an increasing number of farmers. Poor people in this area can easily work in upland paddy and food crops farming that need less capital and can be simply done by family members. Furthermore, lack of government capacity to control spatial plan violations in the peri-urban has given an opportunity for farmers to develop subsistence agriculture in the forest. PUA in the southeast is also located in remote areas, thus increasing poverty has made the farmers stay on their cultivated land.

On the other hand, PUA in the northern part of JMA, which is dominated by lowland/irrigated paddy and food crops, lowland horticulture, marine & coastal horticulture, and livestock, needs more inputs (e.g. seeds, fertilizers, agro-chemicals, machinery, etc.) to reach optimal productivity and generate a higher income. PUA in this area has been developed on fertile soils and has been supported by existing infrastructure such as irrigation channels, road networks, electricity, etc. As more capital is needed to run farming activities, increasing poverty has made the farmers leave their farm to get another job that can give a higher income. They can easily move to the nearby city as PUA in this area is located close to Jakarta (the urban core).

Despite the strong connection of PUA with small-middle scale economic activities, informality, and poverty, PUA surrounding Jakarta, east, and northeast of JMA (cf. Figure 7c Paper II) has the capacity to enhance food security. Better accessibility to the market and/or urban zone has made the PUA in this area market oriented and contribute to the food supply, especially staple food, for urban inhabitants.

PUA in the southwest of JMA has less capacity to support food security as their connectivity to the market is not really strong. Lack of infrastructure development has made this area become a retarded region compared to other areas in JMA (Sunandar, 2006; Rachmawatie, 2010) and farming activities tend to subsistence. However, this area has a potential to enhance agricultural production (Bappeda Kabupaten Bogor, 2009) and substitute PUA in the eastern part of JMA which is strongly threatened by urbanization.

The results of the study give more insight into PUA planning. While the roles of PUA to cope with poverty and food security issues have been frequently discussed, spatial distribution of PUA to deliver specific functions in different parts of urban areas have remained unclear (Lee et al., 2015). Wilson (2006) and Aubry et al. (2012) emphasized that urban planners urgently required methods and tools to define PUA zones and their roles in the development of urban regions. The study has made a first attempt to delineate PUA zones based on different socioeconomic benefits that they produce, thus incorporating PUA into spatial planning of JMA can be easily realized.

Applying Correspondence Analysis (CA) coupled with the Geographically Weighted Regression (GWR) model are useful to map the socioeconomic roles of PUA over the urban landscape. However, it cannot be applied when the statistical data on agriculture are insufficient. Furthermore, this method has a limitation to analyze the relationship of PUA with environmental aspects as specific data and modelling approaches are needed to study hydrology, climate, biodiversity, etc. Therefore, a different approach was adopted in the subsequent analysis of flooding problems related to the dynamics of PUA in JMA.

PUA Roles in the Urban Environmental System

Management of catchment areas has become an important issue as JMA is threatened by increasing flooding and landslide incidences. As most of PUA land has been pushed outward by urbanization, agricultural land use in the three catchment areas in the south (Kali Bekasi, Ciliwung, and Cisadane) expanded from 1983 to 2012 and became the dominant land use.

In order to increase the capacity of catchment areas to retain and infiltrate water, development of settlement has been restricted by the government. However, policies for the sustainable management of farmland as the dominant land use type are still missing. In fact, it should be recognized that the expansion of farmland in the catchment areas may be harmful, for instance for biodiversity (Wang et al., 1997; Foley et al., 2005), and preservation of soil and groundwater quality (O'Connell et al., 2007; Dale and Polasky, 2007; Kenyon et al., 2008; Wheater and Evans, 2009; Balali et al., 2011).

The results from the Peak Flow Model enabled the delineation of critical zones to runoff. Moreover, the proportion of farmland was identified as being responsible for the volume of runoff. Another important factor is slope. Steep slopes in the Ciliwung catchment covered by farmland not only increase the volume but also the speed of runoff. Therefore, flooding caused by the Ciliwung is particularly critical for the city center of Jakarta. While runoff from Cisadane and Kali Bekasi catchments is less critical for flooding, as they are characterized by gentler slopes and the streams do not lead through Jakarta, decreasing capacity to retain runoff is of concern. Rustiadi et al. (2012a) have noted the trend of increasing flood incidences in Tangerang and Bekasi as the downstream areas of the both catchments.

The results of the USLE model show that PUA expansion from 1983 to 2012 generated different quantities of soil erosion depending on the physical characteristic of the catchment areas and the management level of agricultural activities. Introducing good management of farmland (e.g. mulching, intercropping, crop rotation, terracing) in the Kali Bekasi catchment is able to reduce soil erosion when compared with actual management in 1983. Here, farmland management plays a key to reduce soil erosion as the shape of the catchment is wide with gentle slopes.

Conversely, the expansion of farmland in the narrow and steep of Ciliwung catchment intensified soil erosion under good and bad management of farmland. Therefore, the control of further expansion of agricultural land in this area, especially on land on the steep slopes, is of importance.

The situation is similar in the Cisadane catchment where expanding farmland increased soil erosion under good and bad management of farmland. However, the situation was not as serious as in the Ciliwung catchment. Under good management, soil erosion only increased 43% compared to soil erosion 1983, despite the increasing farmland that almost doubled from 1983 to 2012. Introducing good practice of farmland management can curb soil erosion, but further expansion of farmland also needs to be controlled.

Obviously, the expansion of PUA in the three catchment areas strongly increased runoff and soil erosion. Zoning analysis based on the runoff and soil erosion models shows that PUA land was mostly located in the critical zones to runoff and soil erosion (zone 2, 3, and 4). Dryland agriculture has become the predominant farming type, mostly in the form of horticulture. As it involves labor and is capital intensive, most of the farmers exploit their land to secure harvests and capital return. Farming continuously without a break coupled with open land without cover crops, intensifies runoff and soil erosion (Agus and Husen, 2005).

However, reforestation of agricultural land to reduce runoff and soil erosion is hardly to be considered as an alternative as it has been shown that agricultural activities in this area play important roles in the socioeconomic system (see the previous section). Moreover, the results of zoning analysis show that only 9-10% of farmland in each catchment area would need to be reforested to minimize runoff and soil erosion on the steep slopes. Therefore, the solution does not need to only rely on reforestation to maintain hydrological process in the catchment area (O’ Conell et al., 2007). Instead, the link between flood risk management, agriculture, and agricultural management practices should be considered (Kenyon et al., 2008, O’Conell et al., 2007). Still, PUA expansion should be restricted to protect the forest land that also plays important roles for maintaining the hydrological balance and reduce flood (Farid et al., 2010; Rustiadi et al., 2012b).

The models used in this study are able to delineate PUA land based on their different impacts on runoff and soil erosion. Still, further calibration of the Peak Flow Model is required to increase its accuracy. Furthermore, the USLE model needs updating data of soil erosion of recent farming management. These improvements are important to increase the capability of the models to develop scenarios of PUA management which effectively minimize runoff and soil erosion.

5.3 Multifunctional Practices at the Farm Level (Micro Level)

Developing multifunctional PUA will not be successful if farming activities do not have the capacity to survive. Aubry et al. (2012) argued that maintaining farmland in peri-urban area is very expensive due to increased land rent, higher wages, etc., thus farming itself should have a strong capability to continually generate sufficient revenue. Therefore, peri-urban farming should be able to develop multiple benefits in order to get more support from wider beneficiaries. Particularly, farming transition towards strong multifunctionality (Wilson, 2007, 2008) should be encouraged.

Despite their low education, farmers in the Ciliwung catchment still have a potential to adapt to urbanization as most of them are in a range of productive ages, highly motivated, and work full time in agriculture. Furthermore, horticulture and paddy fields have become two dominant farming types. A majority of farmers do not work on their own land, but lack of land ownership has not prevented them to continue farming. They have an access to land mostly by sharing the harvest with the landowner, rent a land, or work as a property guard.

Horticulture and paddy rice farms respond differently to urbanization. Low farming benefit has made paddy rice farms have become smaller and fragmented due to urban encroachment. Therefore, paddy farmers need to find alternative jobs in the informal sectors, while they still continue farming to secure domestic food source. Furthermore, they reduce farming cost by cultivating only two times a year, using less inorganic inputs (e.g. fertilizers, pesticides, herbicides), and employing family members. Fortunately, low intensity of farming can keep soil productivity. Moreover, paddy fields could enhance landscape scenery between settlements and contain runoff in the Ciliwung catchment (cf. Paper III).

On the other hand, in order to respond to the increasing food demand from the urban market and to raise profits from farming, horticultural farms have moved to larger tracts of land further away from settlements and penetrated the forest. Horticultural farmers invest much more capital. Furthermore, in order to deal with the perishable nature of the produce and the complexity of the vast JMA food market which involves many middlemen, traders, and suppliers, the farmers apply multiple cropping to reduce price dependency on individual crop. Consequently, they need more inputs, treatments, and labor. High intensity of farming has decreased soil productivity and soil capacity to retain runoff. Still, many tourists are coming to horticultural farms for visiting, experiencing farm work, as well as directly harvesting and buying products in the field.

Obviously, there are two different motives for farming. Paddy farmers want to secure their food source when they become economically vulnerable due to urbanization. Most of paddy farmers are older, part-time, and relatively poor. Whereas, horticultural farmers have a profit motive. Most of the farmers are younger, full-time, and have more capital.

Farmers' behavior in managing farmland is not only influenced by their motivation but also the land tenure situation. Most of paddy farmers work on land that previously belonged to them. During the peak periods of urbanization in the 1990's they often sold their land to get more money (Firman, 2000). Still, some landowners allowed them to continue farming and ask for some part of the harvest. Depending on the landowner, paddy fields are at risk of being converted to settlement. However, land productivity can be maintained as paddy fields have low farming intensity.

Horticultural farmers can get access to a larger-sized land by renting a land or becoming a property guard of the landlord. On the rented land, the relationship between farmers and landowner is only based on a short-term contract of one or two years duration. Therefore, the tenant farmers exploit the land to quickly return their investment. Conversely, on the guarded land, the relationship between farmers and landowner is more personal, long term, and based on mutual trust. Therefore, the farmers feel responsible to maintain the land and its productivity in order to secure long-term farming activities.

Apparently, horticultural and paddy rice farms show different degrees of multifunctionality regarding Wilson's (2007, 2008) criteria of strong multifunctional agriculture (cf. Chapter 2). Paddy rice farms are strongly embedded in local and regional socio-ecological systems as they become a food source for the poor and provide green open spaces between settlements that could attract urban visitors and improve the environmental condition (e.g. contain run off, maintain land productivity). However, they have low embeddedness to the regional economy and a low degree of diversification.

Horticultural farms are strongly embedded in the local and regional economic system (e.g. income and employment generation), supply urban food demand, and support outdoor recreation. However, they have low environmental sustainability and a low degree of diversification like paddy rice farms.

Additionally, there is a lack of understanding of the urban society about the roles of farming beyond food and fiber production. Therefore, farmland is not assigned a role in the future development of JMA (Hudalah and Firman, 2012; cf. Paper I).

This situation will threaten the sustainability of farming. Low profit of paddy rice farms is less attractive for young farmer generations, whereas exploitative horticultural farms will reduce land productivity. Therefore, developing strong multifunctional agriculture should be emphasized. Wilson (2007, 2008) argued that the transition towards strong multifunctional agriculture is influenced by farm size, farm ownership, and economic turnover. However, the results of the study indicate that farmers' choices in farm size, ownership types, and economic turnover depend on: (1) their individual capacity (e.g. age, working time allocation, and capital); (2) their motives (economic revenue or subsistence), and (3) the land tenure situation.

These findings confirm other studies which emphasize the role of farm household characteristics as determinants of farmers' decision making (Rodríguez-Entrena and Arriaza, 2013; Villanueva et al., 2015). Farmers who are young, working full time, having more capital, and are economically-motivated tend to have an access to a larger land and create higher economic turnovers. Therefore, they are willing to take a risk of insecure land ownership. Still, secure land access is required to reduce exploitative farming practices as often found under short-term contracts of land tenure.

The method adopted in this study is useful to analyze PUA characteristics at the farm level which is rarely done in Asian megacity settings as farming is still regarded as a marginal economic activity. However, this method has a limitation because the questionnaire-based interviews were only done in a certain PUA area in JMA. Further study can cover other areas of PUA in JMA that probably have different characteristics.

5.4 Recommendations for Developing Policies of PUA Management

Policies for agricultural land management have been difficult to implement due to rapid urbanization in peri-urban JMA, especially after the economic crisis of 2007 came to an end, as interviews with government officials of districts and municipalities in surroundings Jakarta revealed. Therefore, a new policy has been established more recently to protect agricultural land for food production (Agriculture and Forestry Office of Bogor Districts, 2012; Bekasi District Government, 2011; Tangerang District Government, 2011). It was based on land suitability assessment and the economic scale of farming. Furthermore, technical assistance, agricultural technology, and capital support are only given to farmers who own the land.

Certainly, the effectiveness of this policy needs to be questioned regarding the empirical situation of PUA in JMA. The results from this study clearly showed that loss and fragmentation of farmland have reduced its economic scale. Most of agricultural land in JMA has been pushed outwards to less suitable / less productive land. Moreover, most of the farmers do not work on their own land. Furthermore, multifunctionality of farmland has not been considered in the policy for farmland protection.

This study highlights that conserving farmland in the peri-urban should consider different characteristics of farming types and their capacity to adapt to urbanization. Lowland horticulture and inland aquaculture can cope with smaller and fragmented agricultural land between urban settlements. On the other hand, lowland and upland paddy & food crops, upland horticulture, and livestock, which need a larger land further from urban settlements should be managed by agricultural zoning to protect farmland, increase farm efficiency, and prevent the shifting of farmland towards forest land.

Subsequently, each farming area should be connected to the urban system based on their different capacity to deal with particular socioeconomic and ecological issues. Regarding socioeconomic issues, strong connectivity between PUA and small-medium scale and informal urban economic activities has been shown as important to mutually strengthen the livelihood of farmers and overall peri-urban economy. It will support resilience, livability, and sustainability of urban regions to face increasing risks of global economic and environmental change (Moench and Gyawali, 2008; Douglass, 2013).

Moreover, a specific approach is needed to deal with the poverty issue which is different between: (1) poor farmers in high potential areas for farming (north of JMA) and (2) poor farmers in low potential areas for farming (southeast of JMA). For the first, enhancing access to capital and agricultural inputs is important so that farmers can increase productivity and thus enhance the profitability of their farms. Whereas, for the second, developing off-farm economic activities (e.g. food processing, food trade, etc.) and non-commodities products and services of farmland (e.g. agro-tourism, education, etc.) are suggested as a strategy to reduce the number of farmers, increase farming efficiency, and release the forest from PUA expansion.

Additionally, the preservation of PUA should be prioritized on land that can provide food for the city. In the case of JMA, these farmlands are located in surrounding Jakarta, as well as east, and northeast of JMA. However, regarding the risk of land conversion to urban use, another approach should be considered which is transforming subsistence agriculture into commercial agriculture. In the case of JMA, subsistence PUA the southwest of JMA can be improved through agricultural technology, infrastructures development, and connectivity with the urban markets.

Regarding environmental issues, the roles of PUA are specific depending on the location and farming types. In the case of JMA, delineation of PUA zones which critically influences runoff and soil erosion has become a key to enhance environmental functions of farming.

PUA in the non-critical zones to runoff and soil erosion should be supported by incentives and management assistance to maintain land productivity as well as soil capacity to retain and infiltrate water. PUA in the critical zones to runoff and soil erosion should be supported by incentives and technical assistance to implement soil and water conservation practices in farming (e.g. preventing soil compaction, minimizing soil erosion, nutrient management, soil organic matter management, controlling runoff, increasing water infiltration, efficient irrigation system, etc.). In addition, a compensation formula that accounts for the position of farmland and its particular effect on runoff and soil erosion might stimulate farmers' involvement in environmental management (Broch et al., 2013). Furthermore, PUA should be converted to woodlands in the reforestation zone. Inevitably, reforestation would mean that farmers will lose their occupation. Therefore, these farmers should be moved to other areas or trained for getting another job.

All of those recommendations should be accompanied by programs to influence farmers' behavior as decision makers in agricultural landscapes. Farmers should be enabled to develop strong multifunctional farming that depends on their individual capacity, farming motives, and land tenure situation.

Farmers' individual capacity should be increased to develop profitable activities on and off the farm. Farmers' capacity on the smaller and fragmented farmland should be supported to develop farming business (e.g. processing of agricultural products, agro-tourism, agro-education, etc.) or to adopt profitable and robust farming types (e.g. lowland horticulture, inland aquaculture) as they can offer farming products and services to the nearby urban consumers. Whereas, farmers' capacity on larger farms should be supported to apply soil and water conservation practices, produce fresh and healthy commodities, and develop direct marketing (i.e. selling directly to urban visitors). Adopting these measures is considered important for maintaining land productivity, fulfilling growing urban demand for high quality of food (Manuturi, 2014; Indonesia Business Daily, 2016), and shortening the chain of trade to get more profit (Wästfelt and Zhang, 2016).

Furthermore, broadening non-commodity products and services of farmland are required to bring more benefit and motivate farmers to continue farming. These may include goods and services for non-food markets such as tourism, education, etc., and supporting non-marketable public benefits such as food security, local economic development, maintaining environmental quality, etc. (Renting et al., 2009). Non-food markets will generate more profit. While, non-marketable public benefits will enlarge government and public support for PUA through compensation for farmers, environmental programs, agricultural programs, including strengthening social ties between urban-rural inhabitants that will encourage business cooperation in developing non-food markets of farming.

Finally, farmers' access to land should be enhanced by designing long-term agreements between farmers and the landowner which is facilitated and legalized by the government. This would increase the landowners' trust that their property will be properly managed, while it would allow the farmers to base their farming activities on a longer-term perspective and to diversify the farm business. Moreover, the government would be able to arrange long and medium-term agricultural programs (e.g. farmland management, application of agro-technology, infrastructures development, etc.)

These recommendations emphasize the enhancement of farming capacity to adapt to urbanization and to generate multifunctionality as key factors for preserving PUA, which are more essential than land suitability assessment, economic scale of farming, and farmers' land ownership. Obviously, the success of farmland preservation would contribute to containing further urban sprawl, thus enhance the management of the desakota region as well as the resilience of Asian megacity.

5.5 The Relevance of the Research for Managing PUA in Asian Megacities

The desakota phenomenon in Asian megacities has been increasingly studied by many scholars (McGee, 2010). However, there is still a lack of knowledge of its dynamics and functional roles based on in-depth empirical study. Consequently, there is a gap between the conception and policy approach to manage this region, thus urban sprawl in Asian megacities continues and leads to severe social and environmental challenges. This research contributes to an improved conceptual understanding of the desakota region and its potential role for urban sustainability by highlighting the specific response and functions of PUA. Results can also contribute to putting into practice the idea of a controlled mixture of rural-urban landscape in desakota regions that has long been suggested by Yokohari et al. (2000).

Integrating PUA into urban planning policy in the developing world has been considered as part of a strategy to enhance urban resiliency, livability, and sustainability (De Bon et al., 2010; Zezza and Tasciotti, 2010; De Zeeuw et al., 2011). Unfortunately, lack of study about the links of multifunctional PUA with urban development issues hampers policy making for PUA. It is suggested that the three tier approach applied in this research can become a reference for research to support the development of multifunctional PUA, especially in Asian megacities where rapid urbanization has led to increasing social and environmental issues. Obvious roles of PUA in dealing with urban socioeconomic and ecological issues will enhance the preservation of farmland in the peri-urban as well as curb further urban sprawl.

The results of this study also make a contribution to better planning for PUA. As PUA produces multiple benefits that cover different ranges of areas, from the city level to the farm level, a multilevel approach has the capacity to support comprehensive policy making for PUA. Multilevel policies for PUA is important to overcome the problems of the urban-rural dichotomy and fragmented governance, both are commonly found in Asian megacities, thus the integration of PUA into urban planning and development can be achieved.

Finally, a better knowledge base for PUA planning will support other planning concepts for urban development which are evolving recently as a response to the emerging global and local economic and environmental issues. PUA has the potential to support the green infrastructure concept as it is able to provide ecosystem services for urban and peri-urban dwellers (see also La Rosa and Privitera, 2013; Lee et al., 2015). It is also able to support the development of food networks and food security programs in urban regions (see also Paül and McKenzie, 2013; Barthel and Isendahl, 2013). Furthermore, it will enhance the transformation of the urban-rural interface in the peri-urban into multifunctional zones (i.e. social, economic, and ecological functions) to support urban sustainability (see also McGee 2010; Ravetz et al., 2013). All these planning concepts are relevant for Asian megacity that nowadays facing serious socio-ecological challenges.

6. CONCLUSIONS

The rigorous analysis of periurban agriculture (PUA) based on a multi-level perspectives in the Jabodetabek Metropolitan Area (JMA) surprisingly showed that PUA keeps persisting under strong urbanization pressure and even supports urban resilience while it is neglected in urban planning policy. The results expanded knowledge on the dynamics of PUA by providing a detailed picture of its adaptation to urbanization. However, for becoming an integral part of the urban system, obviously, PUA needs to be managed. A better understanding is required regarding different characteristic of farming types, their response to urbanization, their linkages with the urban system, their potential to develop multiple functions, and key factors that could expand these functions.

During rapid urbanization, the roles of PUA to support food security at the time of crisis as well as to support peri-urban livelihoods are obvious, but shifting of farmland to forestland jeopardizes the environmental situation in JMA. Consequently, a planning policy for PUA is required to expand its benefits and control its negative impact. It should be adapted to local conditions and agricultural types. Some of farming types have moved to remote areas due to urbanization such as lowland and upland paddy & food crops, upland horticulture, and livestock. Interestingly, farming types such as lowland horticulture and inland aquaculture have a capacity to persist in the small and fragmented agricultural land in urbanized areas, and they even benefit from growing urban markets in the nearby.

For the first time, 10 types of PUA were distinguished in a desakota region, and their specific behavior under urbanization was assessed. Regarding their distinctive response to urbanization, the capacity of PUA to deal with socioeconomic and environmental issues is different between types and location. PUA types that produce staple food in the surroundings Jakarta, east, and northeast of JMA are capable to support food security. Capital intensive PUA in the north of JMA can overcome poverty as long as farmers get financial supports, whereas subsistence PUA in the southeast of JMA should be supported by developing off-farm activities and non-commodities products and services of farmland to free farmers from poverty. All PUA also have a close connection with consumers and small-medium scale informal economy activities, thus their strong interlinks will enhance the PUA preservation.

Furthermore, PUA in the different zones of three catchment areas in JMA (Kali Bekasi, Ciliwung, Cisadane) play a key in controlling runoff and soil erosion to lessen flooding and landslide risks in JMA.

Understanding farming types, size, distribution, and their specific linkages to urban development issues will support urban planning for integrating PUA into urban planning policy. This would increase the support of PUA from the public and the government to enhance its existence in urban and peri-urban areas. However, this policy will not be successful if the farmers do not have the capacity to maintain their farming business due to low revenues or declining land productivity. Therefore, a transition process from rural-traditional farming that only focuses on food and fiber production to multifunctional practices that consider social, economy, cultural, and ecological values of farmland should be encouraged. Multifunctional farming will give farmers the opportunity to get more revenues, incentives, and compensation from wider beneficiaries either individual (for marketable products and services), or society (for non-marketable products and services).

The study shows three interrelated factors consisting of individual capacity of farmers, farming motives, and land tenure situation, that determine multifunctional transition at the farm level. Farmers who are still young, full-time, and have more capital are highly motivated to develop farming business. However, depending on land tenure, secure land access will lead to sustainable farming as farmers want to maintain land productivity in the long term, whereas insecure land access will lead to exploitative farming. Therefore, increasing farmers' capacity, motivating farmers to develop farming business, and securing land access become key factors to develop multifunctional practices that can preserve farming activities, on one hand, and sustain multiple socioeconomic and ecological benefits of PUA, on the other.

This study offers an alternative approach for landscape planning and development of Asian megacities which now is facing uncontrolled urban expansion (urban sprawl) and growing socio-ecological issues exacerbated by the emerging global economy and environmental changes. Since the conception of desakota regions came into discussions to the growing ideas to particularly manage this region for supporting urban sustainability (Douglass, 1998, Yokohari et al., 2000), preserving farmland in rapidly developing urban regions still is a challenging task. A conception of urban agriculture that proposes the integration of agriculture into the urban socioeconomic and ecological system offers a more effective solution. However, its implementation is still problematic due to the lack of knowledge on multifunctional agriculture and their link to the urban system. Therefore, this study has made a first attempt to bring the urban agricultural concept into practice by employing a multi-level approach within the Asian megacities context.

Based on the approach, results of the study lead to recommendations for PUA management on different levels of planning hierarchy. At that at the city level, the roles of PUA to support urban resilience to poverty, food security, and environmental challenges can not be neglected. Therefore, PUA land should be managed by improving knowledge on different capacities of farming types to adapt to urbanization. At the local level, the effect of PUA types on socioeconomic and ecological issues in different parts of urban regions should be defined to integrate PUA into spatial planning policy and assign roles in the future urban land use. At the farm level, developing multifunctional practices is important to maintain farming sustainability as well as multiple functions of PUA at the city and local level. This multi-level approach can be widely adopted for PUA planning, especially in Asian megacities which have experienced urban sprawl, a desakota phenomenon, and fragmented governance.

Still, there are some remaining questions for future research. First, a simulation model should be developed to analyze the effect of PUA planning scenarios in urban development, especially in strengthening resiliency, livability, and sustainability. Developing such an approach is important as considering PUA as an integral part of the urban system may lead to conflicts or synergies with other urban agendas. Second, different regulations, programs, and public budget allocations, including cooperation between different government institutions and related stakeholders (farmers and non farmers) should be further explored to formulate the optimal policy for managing and developing PUA. A comprehensive planning is required as PUA can deliver public benefits from the farm level to the city level.

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ANNEX: RESEARCH PAPERS

Paper I

Pribadi, D.O., Pauleit, S., 2015. The dynamics of peri-urban agriculture during rapid urbanization of Jabodetabek Metropolitan Area. *Land Use Policy* 48: 13-24.

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The dynamics of peri-urban agriculture during rapid urbanization of Jabodetabek Metropolitan Area

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ABSTRACT

Rapid urbanization in Asia puts strong pressure on densely populated agricultural land in the peri-urban zone. It has created a specific feature, namely 'Desakota', as a mixed urban–rural zone which has been proposed to play an important role to support urban sustainability. However, preserving agriculture during urban expansion is hampered by the lack of understanding of its character and its economic, social, and ecological roles within the urban system. This research analyzed urbanization patterns in Jabodetabek Metropolitan Area (JMA) with Indonesia's capital Jakarta at its core, and the dynamics of peri-urban agriculture in this context. Land use change analysis, descriptive and multivariate statistical approaches of social-economic panel data, and spatial mapping and clustering of agricultural types were applied. Results showed that rapid urbanization still continues at low development densities. It has led to the large-scale loss of farmland and increased land fragmentation. Interestingly, peri-urban agriculture still persisted and was even strengthened when JMA was hit by the economic crisis. While the area of agricultural land suffered heavy losses, the overall decline was less than expected due to conversion of woodlands into farmland. The number of farmers even increased but mostly because of a steep rise in landless farmers. Moreover, many peri-urban dwellers were still involved in on-farm and off-farm activities. We distinguished 10 agricultural types. Lowland horticulture and inland aquaculture were able to adapt and even benefit from urbanization due to proximity to the nearby urban market, whereas paddy fields, food crops and livestock were mostly displaced by urbanization and moved to the non-urbanized area. These results shed new light on the dynamics of peri-urban agriculture and indicate its persistent role in the peri-urban economy as well as supporting urban resilience during an economic crisis. Therefore, peri-urban agriculture should be regarded as a vital element of a megacity. Some strategies for its protection and development are suggested.

1. Introduction

Asia is characterized by strong urbanization. In 2011, 45% of Asia's population lived in urban areas and this figure is expected to increase to 64% in 2050 (UN (United Nations), 2011). Sixty percent of the megacities, defined as a metropolitan area having 10 million inhabitants or more, are located in Asia (McGee, 2010), especially in East, South East and South Asia (Kraas, 2007). There is a strong and still increasing pressure on farmland. According to Dahiya (2012), on average, Asia's urban population growth expands by over 45 million a year, and this causes the loss of agriculturally productive land of more than 10 km^2 a day.

Within the Asian context, extended metropolitan regions often penetrate important agricultural areas in emerging peri-urban zones that already have dense rural populations due to labor intensive agricultural activities such as the cultivation of rice. These zones form a specific feature of Asian city regions called desakota which is derived from the Indonesian words "desa" meaning village and "kota" meaning city (McGee, 1991). Within a desakota, rural and urban livelihoods, communication, transport, and economic systems are closely intermingled (Moench and Gyawali, 2008) to form a seemingly chaotic land use pattern (Yokohari et al., 2000).

Jabodetabek Metropolitan Area (JMA) of Indonesia is one of the biggest megacities in Asia. It is known for its rapid urban growth and the emergence of the desakota region. Previous studies in JMA found that urban expansion led to the conversion of large tracts of agricultural areas (Firman and Dharmapatni, 1994; Firman, 2000, 2002, 2009; Hudalah and Firman, 2012; Indraprahasta, 2013),

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mostly caused by the development of large scale housing and new towns, infrastructure, and industrial estates (Firman, 2009; Hudalah and Firman, 2012).

The high pace of urbanization and population growth in Asian cities has accelerated the increase of food needs, poverty, and environmental degradation (McGee, 2010; Dahiya, 2012). Therefore, McGee (2010) argued that desakota regions will become crucial zones to achieve sustainable development because of their resource base and proximity to the urban core support "food security" policies in the face of global volatility in gas and food prices. Yokohari et al. (2000) even suggested that the controlled development of mixed urban-rural landscapes should become a new ecological planning concept for future Asian megacities. More widely, the rural–urban interface within megacities requires the development of specific approaches to their management in order to support urban sustainability (Douglass, 1998; Allen, 2003). A new rural–urban compact needs to be developed to deliver food and fiber, improve job and income opportunities, reduce the rural–urban divide, and reverse the current trend of urban environmental degradation (Gutman, 2007).

Concurrently, recent studies indicated that peri-urban agriculture (henceforth called PUA) can improve environmental quality, e.g., by mitigating the urban heat island effect and by reducing vulnerability of urban areas to flooding (Yokohari et al., 2000; Malaque III and Yokohari, 2007). PUA also can help to create an amenity-rich, biodiverse landscape, and to provide outdoor spaces for recreation for the urban population (Yokohari et al., 2000; Malaque III and Yokohari, 2007; Zasada, 2011; Ives and Kendal, 2013; Tassinari et al., 2013), to develop food security and nutrition (Malaque III and Yokohari, 2007; Zasada 2011; Paül and McKenzie, 2013), and to provide sources of income especially for the poor (Zezza and Tasciotti, 2010; FAO, 1999; Bryld, 2003).

However, as cities, and in particular Asian megacities, are the engines of economic growth, governments still narrowly focus on promoting the economy despite large social and environmental challenges (Dahiya, 2012). Particularly in JMA, according to the national spatial planning policy (RTRWN 2008) this area will be further developed as a national strategic region (Kawasan Strategis Nasional) to support national economic growth. Therefore, the development of infrastructure and industrial estates is a dominant goal for the peri-urban, and it may be suggested that PUA has been regarded as a transitional activity during the process of urbanization by policy makers in JMA. PUA has not been assigned a role in the future city (Hudalah and Firman, 2012).

In line with this argument, spatial planning regulations in Indonesia do not consider agriculture as an urban component that has economic and ecological functions (Indraprahasta, 2013). Moreover, in the 'Guidelines for the Provision and Use of Green Open Spaces in Urban Areas' published by The Minister of Public Works in 2008; urban agriculture is not categorized as a form of green open spaces.

The missing recognition of PUA in policy making is rooted in a general lack of knowledge and skepticism about the role of agriculture in urban areas. Preservation of open space mostly focuses on natural areas rather than agricultural land (Koomen et al., 2008). The effectiveness of urban agriculture to alleviate urban poverty is questioned because it is not considered as a major economic activity (Zezza and Tasciotti, 2010). Moreover, there are doubts about the capacity of urban agriculture to substantially increase food security due to continuous farmland destruction during urbanization (FAO, 1999; Vagneron, 2007; Paül and McKenzie, 2013). On the other hand, the creation of policies for supporting urban agriculture is also hindered by the lack of reliable data where much of the evidence is still qualitative (Zezza and Tasciotti, 2010), and the literature on urban agriculture is more driven by advocacy rather than rigorous analysis (Ellis and Sumberg, 1998; Webb, 2011).

Obviously, more in-depth analysis of the dynamic response and the roles of PUA in the process of urbanization is needed to fill the gap, especially in the context of Asian megacities that are characterized by the desakota phenomenon. In particular, there is a need to better understand the specific interactions between different types of agriculture and urbanization (Zezza and Tasciotti, 2010).

Based on the above reasons, this paper attempts to further investigate the dynamics of PUA as a response to rapid urban expansion in JMA. The objectives of this paper are: (1) to examine how urban growth affects the land use change of PUA, (2) to define the social-economic relevance of PUA in the midst of urban growth, and (3) to analyze the distribution of PUA types and how they adapt to urban growth in order to support the development of policies for PUA that are adapted to local conditions and agricultural types.

2. Materials and methods

2.1. Research area

The case study area of Jabodetabek Metropolitan Area (JMA) encompasses Jakarta as the capital city of Indonesia and its surrounding region, including 10 municipalities and the 3 districts of Bogor, Depok, Tangerang, and Bekasi (Fig. 1). JMA covers a total area of 6256 km^2 with a population of 27.96 million (2010), distributed over 183 sub-districts and over 1495 villages (2011) (Rustiadi et al., 2012).

The northern part is comprised of an alluvial zone, while the southern part is comprised of mountainous areas. Several streams cross the area from south to north, mostly as a part of two watersheds, namely Ciliwung and Cisadane. In order to protect the catchment area of those watersheds, the forest in the south has been partly protected by establishing Halimun and Gede-Pangrango National Parks. However, increasing incidences of flooding have been observed due to ongoing land use changes which increase runoff.

In this study the term peri-urban zones refers to an area in the outskirt Jakarta, plus 5 municipalities (Bekasi, Bogor, Tangerang, South Tangerang, and Depok) and the 3 districts (Bekasi, Tangerang, Bogor) in surrounding Jakarta, which are defined as a peripheral area of Jakarta (Hudalah and Firman, 2012). Particularly for analyses that used data on municipal or district levels, the peri-urban zone excluded the Jakarta region as the urban core. For further analysis at the more detailed spatial level, such as of villages or of pixel size (15 m × 15 m), the peri-urban zone also included an area in the outskirts of Jakarta that is still located within the boundary of the Jakarta region.

2.2. Land use change analysis

Urban expansion was identified based on a series of land use maps for the entire JMA region. In order to develop the maps, images from Landsat TM were selected because they covered the entire study period of urban development in the whole area of JMA. Five Landsat images for the years 1972 (MSS), 1983 (TM), 1995 (TM), 2005 (TM), and 2012 (ETM+) were used. The MSS and TM data were re-sampled to a 15 m × 15 m pixel to allow multi-temporal comparison with ETM+ data, which was enhanced by using a 15-m panchromatic band. Afterwards, based on 443 field points used as a training data set for defining the spectral signature of each class, and selecting a combination of spectral bands to provide maximum separability of each class, recent Landsat images (2012) were classified into 12 classes of land uses: water body, fishpond, forest, bush, scrub, dryland agriculture, mixed garden, plantation, open space, paddy field, inundated paddy field, and built-up area. As noted, paddy field refers to rainfed paddy fields with low productivity

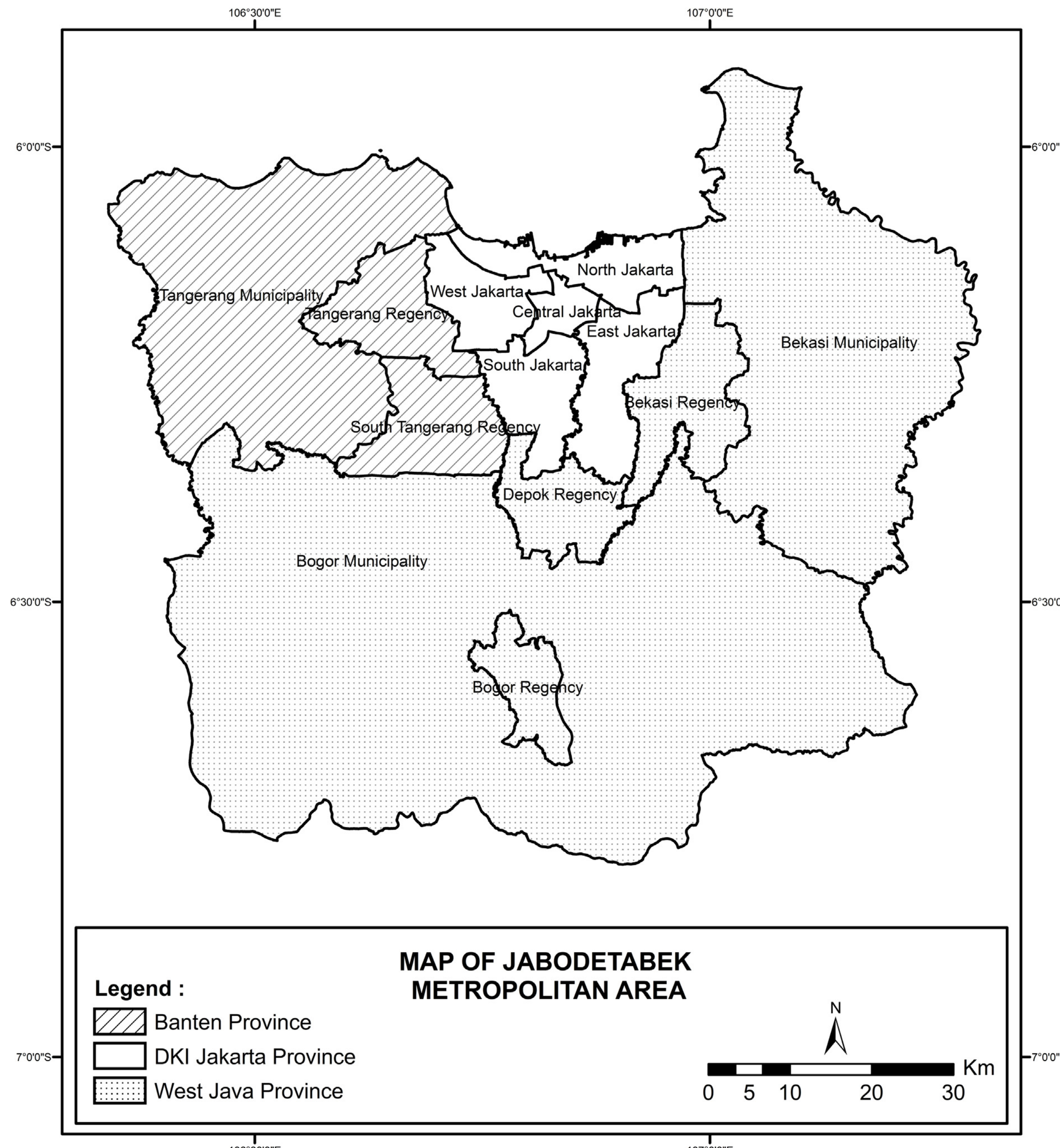

Fig. 1. Map of Jabodetabek Metropolitan Area.

and low cropping intensity, whereas inundated paddy field refers to irrigated paddy fields with high productivity and high cropping intensity. In order to define the accuracy of this classification, 75 independent ground control points were set up. Classification of the older images was done by collecting information of former land use from field interviews and from older JMA land use maps (Rustiadi et al., 2012).

Based on the land use maps, the urbanization process in JMA was described by mapping the expansion of the built-up area. In addition, the pattern of urban expansion was analyzed based on the change of development density, assessed by defining the change of population density within the built-up zone. By using Villages Potency Data (PODES), a database of physical and socio-economic features of a village such as land use, infrastructure, population, livelihoods, and so on, for the years 1993, 2003, and 2008 published by the Central Statistic Agency (BPS), we generated two variables: (1) the built-up ratio which equals the ratio of built up area to the total area of a village, and (2) population density which equals the ratio of the number of inhabitants to the total area of a village. Then, the relationship between the two variables in each year were visualized in two-dimensional scatterplots and expressed by a logarithmic equation.

The impact of urban expansion on PUA was analyzed by identifying loss of agricultural land and by its fragmentation from 1972 to 2012. Conversion of different types of agricultural land to urban use was calculated by using a cross tabulation function in Idrisi Taiga 16.0. Six agricultural land use types, paddy field, inundated paddy field, dryland agriculture, mixed garden, plantation, and fishpond, were distinguished. Agricultural land fragmentation was identified by measuring the degree of mixed land use in JMA. A neighborhood area with size of 50 m × 50 m (0.25 ha) was set in raster data of JMA land use maps, and the land use types were reclassified into built-up and non built-up area. Overlapping neighborhood statistic in ArcGIS 9.3 was applied to calculate the number of neighborhoods that cover single land use and mixed land use types over time. The small size of the neighborhoods was chosen, as it is known that desakota regions are characterized by a small scale mix of various land uses (Yokohari et al., 2000). The average size of farmland per farmer household within the peri-urban is 0.1–0.2 ha (excluding Bogor, Bekasi, and Tangerang district, which still have rural area) according to the most recent agricultural survey (BPS, 2013).

Further analysis of agricultural land use change was done by calculating gains and losses of each agricultural type from 1972 to 2012 under urban expansion. It was measured by using the change analysis module in LCM (Land Change Modeler) simulation model of Idrisi Taiga 16.0.

2.3. Descriptive and multivariate socioeconomic statistic

The changing contribution of PUA to the regional economy was measured by using the GDP (Gross Domestic Product) sectoral data of the municipality/district in JMA from 1993 to 2010 as established by the BPS. The share of the agricultural sector in total GDP in the peri-urban region was calculated from 1993 to 2010. Further analysis was then performed to establish the relationships between the agricultural sector in the peri-urban and in other economic sectors in JMA. Within this analysis, the GDP data were divided into urban GDP of Jakarta and peri-urban GDP of peripheral areas of Jakarta. Then, principal component analysis (PCA) technique was used to extract new independent factors of composite areas (urban and peri-urban) and sectors (9 sectors of GDP). The score of each factor was plotted on a graph to define the status of PUA within the development of other sectors in JMA from 1993 to 2010.

The social importance of PUA was identified based on PODES data in 1993, 1996, 2000, 2003, 2006, 2008, and 2011 established by BPS, including data of (1) farmer household numbers and (2) number of villages that rely on agriculture as a source of income of more than 50% of the population. Farmer households consisted of: (1) agricultural households defined as farmer households that work on their own farm; and (2) farm worker households defined as landless farmer households. Agriculture as the main source of income includes on-farm and off-farm activities e.g., trade and transport of agricultural products; sales of fertilizers, seeds, pesticides, and agricultural equipment; and processing of agricultural products.

2.4. Spatial mapping and clustering of agricultural types

Recent agricultural types were analyzed by mapping the number of farmers belonging to different farming types in each village of JMA. Data on farmers were considered to represent the actual farming activities more clearly than data on agricultural land use types which has been mentioned before. These data were obtained from Population Census Data 2010 established by the BPS that distinguishes between 6 farming types comprising paddy & food crops, horticulture, plantation, fisheries, livestock, and forestry & others. Further classification of these agricultural types was done by completing the data with field observation and data of agricultural production of each municipality/district 2012 published by BPS.

The spatial distribution of each farming type was analyzed in relation to its proximity to other agricultural types, and other factors that represent accessibility (distance to arterial roads, local roads, population number), and infrastructure or environmental support (the presence of rivers, lakes, and irrigation). PCA analysis was used to assess the spatial association among different farming types. Pearson's correlation coefficient was calculated to identify the relationships between the number of farmers of each farming type, on the one hand, and distance to arterial roads, local road and populated area, on the other. Then, Pearson's chi square was used to analyze the correlation between the presence of farming types and the presence of rivers, lakes and irrigation in each village. As noted, irrigation encompasses all irrigation types including technical and conventional irrigation.

3. Results

3.1. Urban expansion in JMA and its impact on PUA

Urban expansion beyond Jakarta began in the early 1980s. The early development of JMA was directed to the east and west of Jakarta by building toll roads in these directions (Suselo, 2006) in order to control urban growth toward the south as an important area for water supply. It can be seen that urban expansion in 1983 tended to move to the east and west of Jakarta (Fig. 2).

From the early 1990s, settlement areas have strongly developed. This period was characterized by accelerating economic growth and excessive land development until the economic crisis in 1998 (Firman, 1999, 2000). Large tracts of agricultural land on the outskirts of Jakarta were converted into industrial estates, large-scale subdivision and new towns, and low-cost housing development areas (Firman, 1999). In 1995 and 2005, urban areas also developed in all directions, including the south. Clearly, the attempt had failed to direct urban growth only toward the east and the west of Jakarta. However, the most recent land use map of 2012 indicates a stronger tendency of urban growth towards east and west of Jakarta for a second time.

While the urban area in JMA strongly expanded, the population density within settlements decreased. Fig. 3 shows that the log function between building density and population density of villages had moved to the left from 1993 to 2008, which means that the population density became lower for the same built up ratio. The decline of population density mainly happened in the villages that have a built up ratio from 0.60 to 1.00, from an average value of 147 capita per hectare in 1993 and 115 in 2003, to 112 in 2008.

Along with urbanization, urban land use increased from 9373 ha to 223,953 ha between 1972 and 2012, with an average annual growth rate of 8.2%. The annual growth rate was 7.6% between 1972 and 1983, 15.4% between 1983 and 1995, and slowed down to 3.9% between 1995 and 2012. This corresponded to an increase of the percentage built up area from 1.4% in 1972 to 32.9% in 2012.

In the same period, 178,509 ha of agricultural land was lost. Dryland agriculture lost most in terms of total area (−78,139 ha, −41.5%), followed by paddy fields (−69,568 ha, −46.4%), which had the strongest proportionate loss of land, mixed gardens (−29,264 ha, −42.0%), and fishponds (−1538 ha, −18.1%). In total, 83.1% of the urban land was formerly agricultural land while most of the remainder was forest.

Rapid urban expansion in JMA was also followed by an increasing mix of land uses. The overlapping neighborhood statistics showed that the percentage of neighborhoods with mixed built up and non-built up area constantly increased from 19.0% in 1972 to 76.4% in 2012 (Table 1). The increase was strongest from 1983

Table 1
Percent of neighborhood number based on neighborhood type within 6256 km^2 area of JMA.

Type of neighborhood	Percent of neighborhood number				
	1972	1983	1995	2005	2012
Only built up/non built up area	81.1	69.1	28.9	26.0	23.6
Mixed built up and non built up area	19.0	30.9	71.1	74.0	76.4

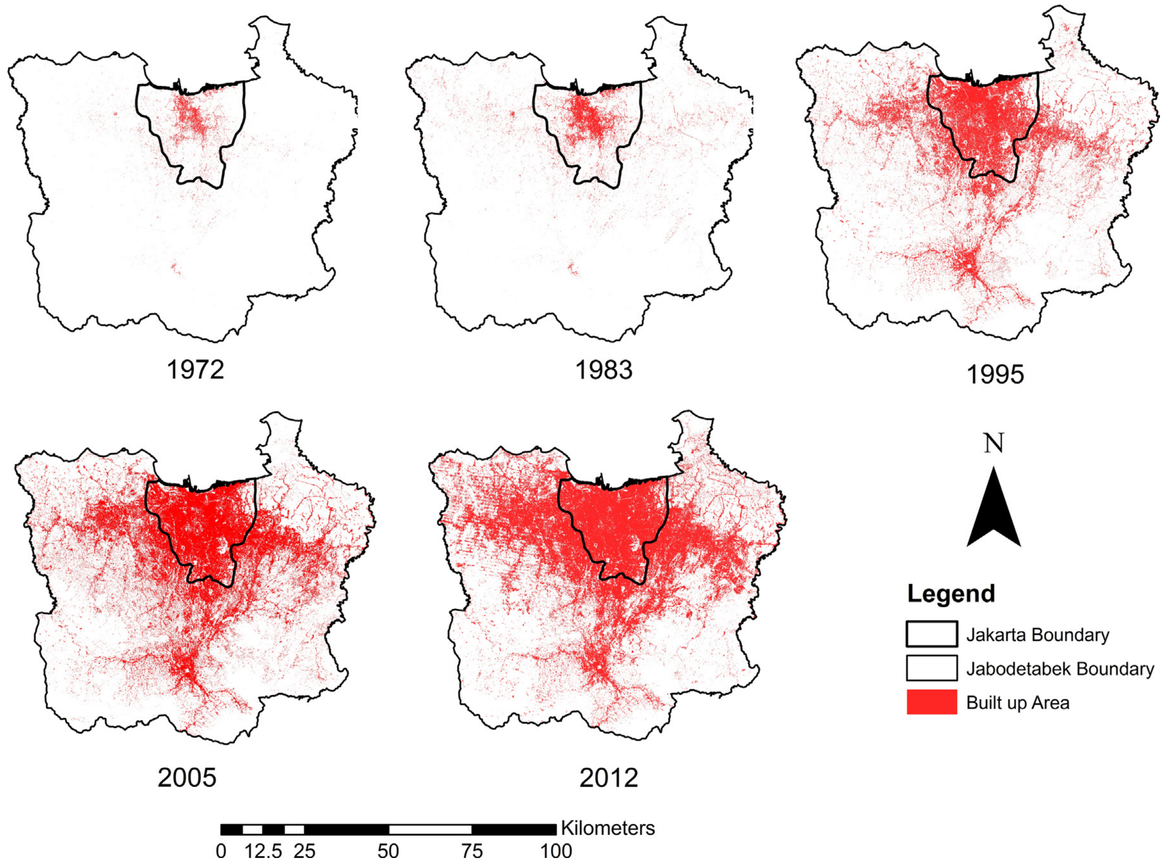

Fig. 2. Map of built up area development of JMA.

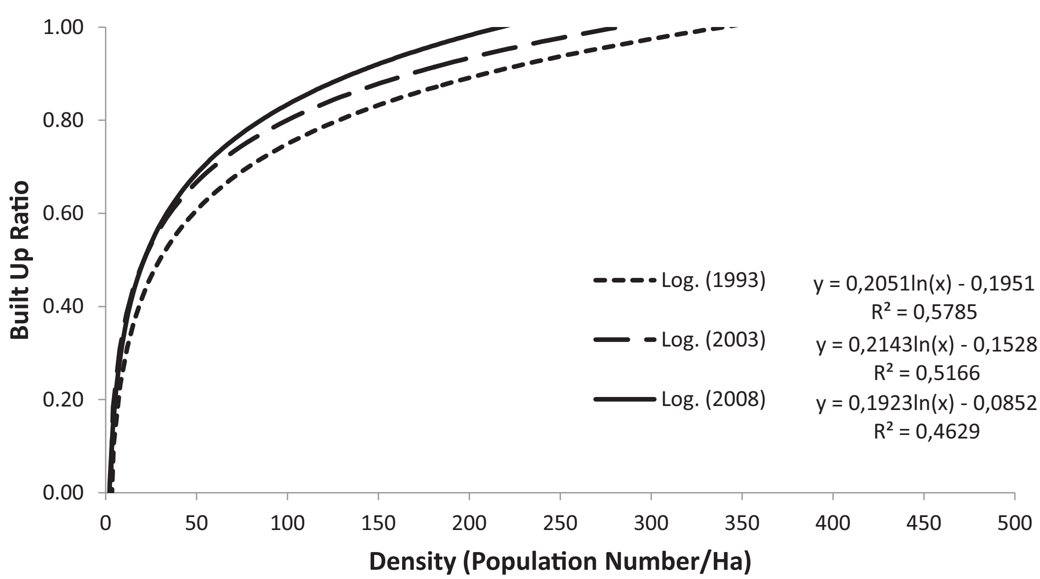

Fig. 3. Logarithmic function of relationship model between built up ratio and population density within settlements in 1993 (*x* settlements), 2003 (*y* settlements), and 2008 (*z* settlements)

to 1995 because of vast urban expansion in the 1990s. This result indicates that urban expansion not only led to the conversion of agricultural land, but also to its fragmentation into smaller patches.

Surprisingly, the losses of agricultural land were lower than urban land take since the total reduction of agricultural land in JMA was "only" 58,976 ha. The percentage of agricultural land fell from 61.10% in 1972 to 52.45% in 2012, which corresponds to a loss of 8.66% agricultural land even after more than 30 years of rapid urbanization. Most converted agricultural land was replaced by the development of new agricultural land in other areas within the region (Fig. 4).

Consequently, forestland has been under strong pressure. It has overall lost 165,784 ha (Fig. 4). The percentage of forestland decreased from 34.4% in 1972 to 10.1% in 2012. A more detailed

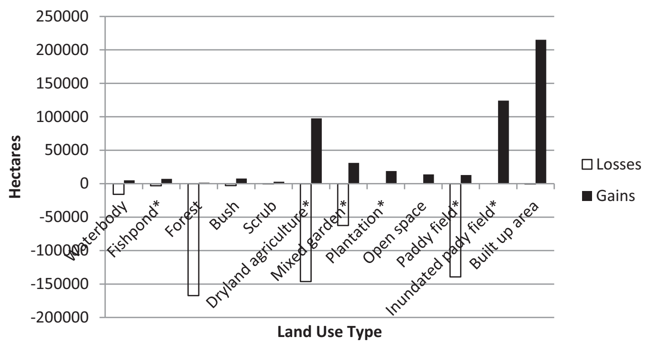

Fig. 4. Losses and gains for land use types in JMA from 1972 to 2012. (*: agricultural land use).

analysis of the dynamics of forestland showed that 74.8% of the forestland lost changed to agriculture.

Fig. 4 also shows that even though "dryland agriculture and paddy fields" (non-inundated) strongly lost, this loss was partially compensated by conversion of forest areas to dryland agriculture and inundated paddy fields away from the urban space. Overall, the dynamics of agricultural land were mainly determined by the gains and losses of dryland agriculture and paddy field (inundated and non-inundated) where both agricultural types represent labor intensive small holder agriculture.

3.2. *Socioeconomic relevance of the PUA*

The share of the agricultural sector to peri-urban GDP has declined from 6.5% in 1993 to 3.0% in 2010 (Fig 5a). However, the decline slowed down when JMA was hit by the economic crisis in 1997–1998 and 2007 which were caused by the global economic crisis. They led to an increase of food prices on the domestic market. In absolute terms, peri-urban GDP generated by the agricultural

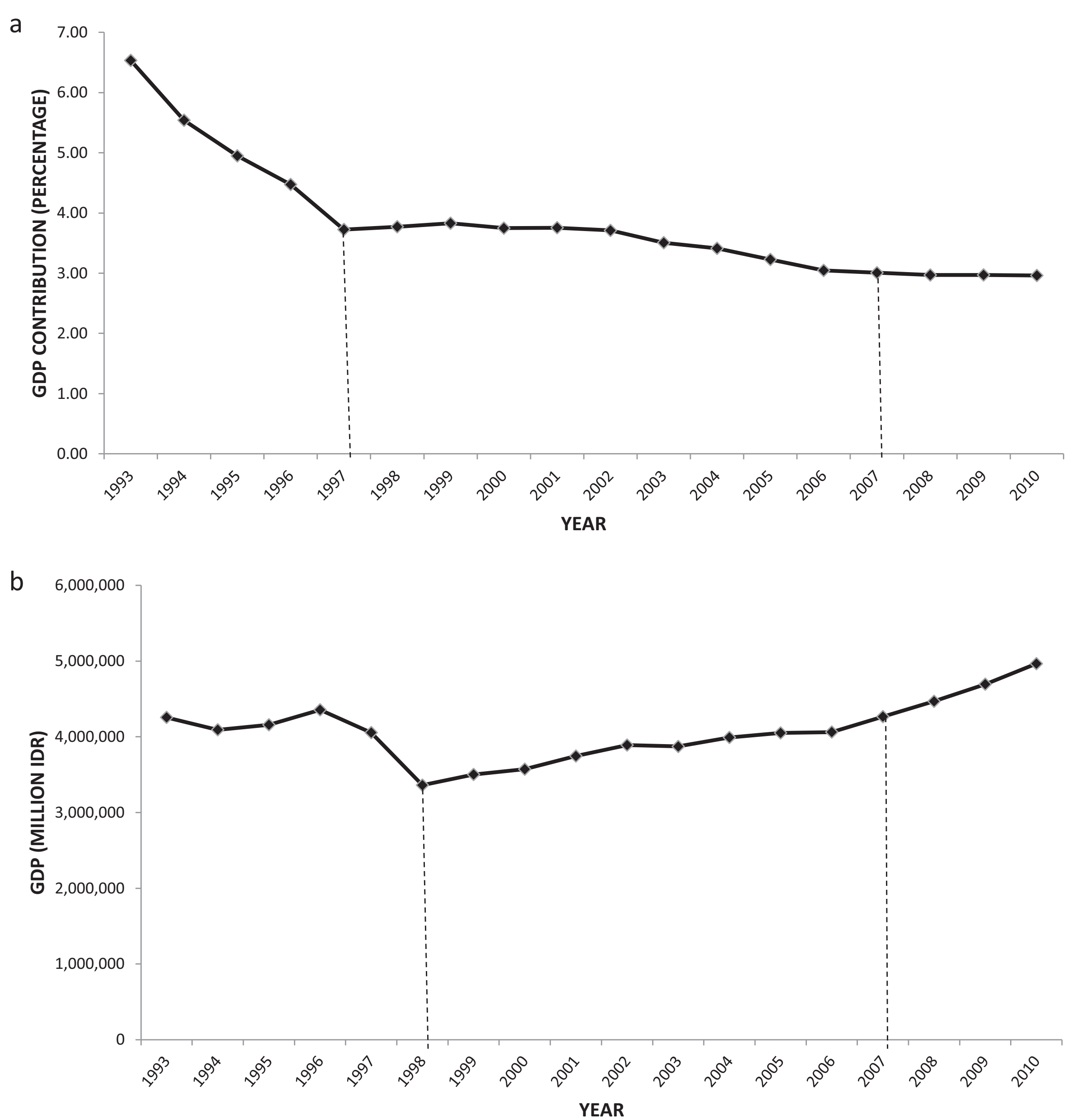

Fig. 5. Development of GDP generated by the agricultural sector from 1993 to 2010 in the peri-urban of JMA as (a) percentage share of overall GDP and (b) total value.

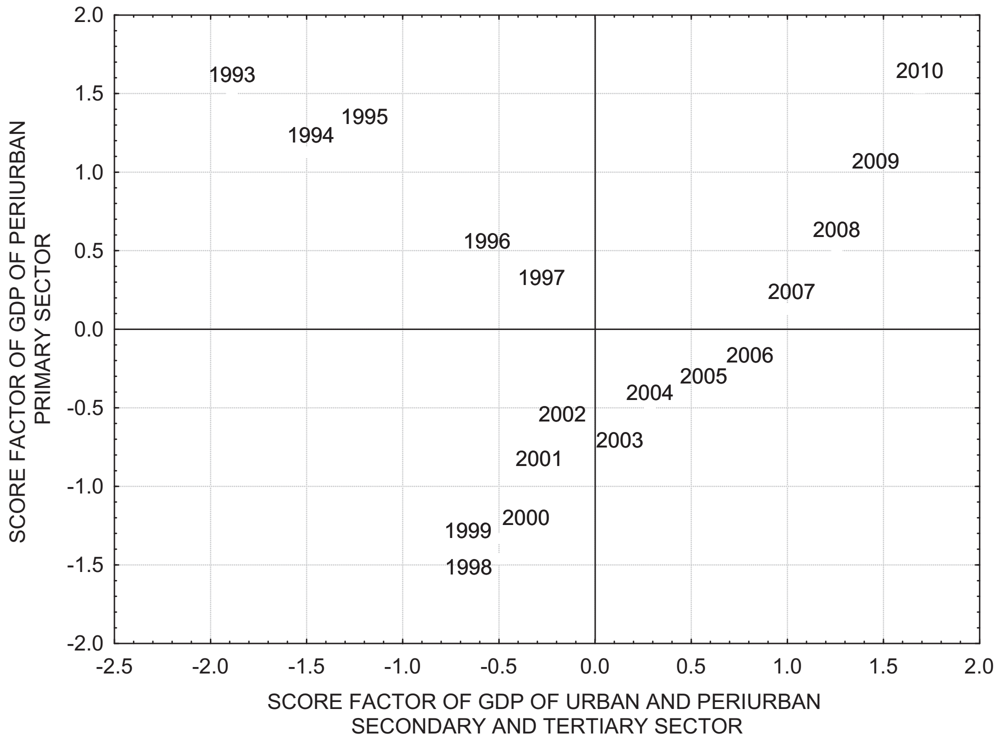

Fig. 6. Time series correlation between the score factor of GDP of peri-urban primary sector (PUA) and GDP of urban and peri-urban secondary and tertiary sectors resulted by PCA.

sector increased after 1998, and the increase since 2007 was even higher than in 1998 (Fig. 5b).

Fig. 6 shows that the GDP of PUA (peri-urban primary sector) decreased along with increasing GDP of other sectors (urban and peri-urban secondary and tertiary sector) from 1993 to 1998, parallel to a massive urban expansion where the non agricultural sector had grown rapidly, and led to the massive conversion of agricultural land. Interestingly, when JMA was hit by an economic crisis in 1998, the GDP of PUA dropped to the lowest level, but afterwards it started to increase concurrently with other sectors in JMA. In particular, the GDP of PUA and other sectors in JMA have grown concurrently at an elevated rate since the last crisis in 2007.

In conjunction with the persistence of agricultural land and the strengthening economic role of PUA after the crisis, the total number of farmer households in the peri-urban increased from 1996 to 2008, and then decreased again in 2011 approximately to the level of 2006 (Fig. 7a). Overall, the number of PUA farmer households increased from 1996 to 2011. However, the proportion of agricultural households who own their farm decreased and has been partially replaced by farm worker households or landless farmers. Members of farm worker households work as labor on one or several farms.

The overall percentage of farmer households in the peri-urban has decreased from 35.6% in 1990 to 19.4% in 2011 (Fig. 7b). However, the number of people who receive income from agriculture exceeds the number of farmers because many people still work on off-farm activities such as farm shop, wholesalers, traders, food vendors, agricultural transport, and so on. Based on PODES data 2011, there were 537 villages in the peri-urban region, corresponding to 43.5% of the total number of villages, where more than 50% of their population received income from on-farm and off-farm activities. This figure indicates that agriculture activities still play an important role in the livelihood of many peri-urban dwellers.

3.3. *Agricultural Types in JMA*

Agriculture in JMA is still dominated by the cultivation of paddy fields & food crops (72% of farmers belonged to this category in 2010), followed by horticulture (9%), fisheries (7%), livestock (7%), plantation (3%), and forestry & others (2%). Paddy & food crops is a typical farming type in Java, which is an important island in Indonesia where JMA is located. Food crops include maize, cassava, sweet potato, and peanuts which usually are cultivated in the dry season when the water supply for paddy is insufficient. Moreover, in the late 1970s and the 1980s the Indonesian government strongly supported the cultivation of paddy fields to reach food self-sufficiency.

However, paddy & food crops have been facing economic difficulties as the crops generate insufficient benefits for farmers due to government policy to keep the price of staple food low and stable. Therefore, they were mostly persisting in the outer ring of JMA where pressures from urbanization have been less strong (Fig. 8). Furthermore, plantation and forestry & others were also located within the outer ring but only in the north area which has been less influenced by urbanization. Fisheries & livestock were mostly located closer to the city core, and the only agricultural type that was located very close to the city is horticulture.

Four main types of agriculture can be further distinguished by product, farming technique, and supporting infrastructure. The first is paddy & food crops with the subtypes of lowland paddy fields, dominated by irrigated paddy field in the plane area in the north, and upland paddy fields, dominated by rainfed paddy field in the hilly area in the south. The second is horticulture which consists of lowland horticulture with lowland vegetables such as spinach, water spinach, string beans, and so on, and upland horticulture with upland vegetables such as chili, carrots, and leek. The third is fisheries which consists of marine fisheries and coastal aquaculture in the north, and inland aquaculture. The fourth is forestry & others which consists of forest plantings, on the one hand, and hunting or

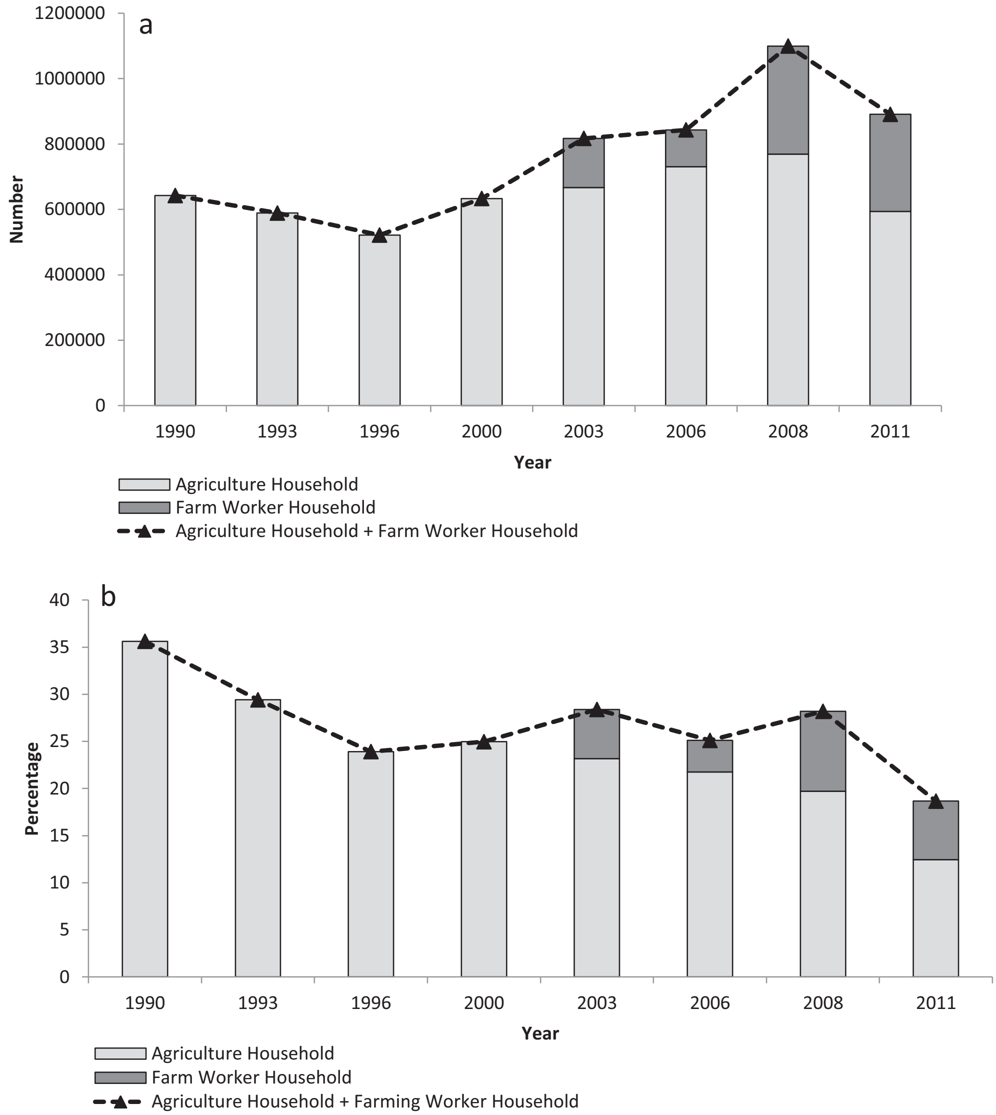

Fig. 7. Agricultural and farm worker household in PUA from 1990 to 2011 by number (a) and percentage (b).

Table 2
Correlation between agricultural type and spatial features of the area.

Variable	Pearson correlation			Pearson Chi Square correlation		
	Distance to arterial road	Distance to local road	Population number	Presence of river	Presence of irrigation	Presence of lake
Lowland paddy	0.37*	−0.32*	−0.28*	12.25 (0.000)*	154.26(0.000)*	0.41(0.523)
Upland paddy	0.32*	−0.08*	−0.18*	32.95(0.000)*	71.28(0.000)*	0.52(0.472)
Lowland horticulture	−0.11*	−0.04	0.2*	0.05(0.820)	3.52(0.061)	1.57(0.210)
Upland horticulture	0.13*	−0.06*	−0.09*	3.33(0.068)	10.90(0.001)*	0.57(0.450)
Plantation	0.11*	0.02	0.02	6.96(0.008)*	3.75(0.053)	0.11(0.746)
Inland aquaculture	−0.11*	−0.02	0.21*	0.60(0.437)	0.90(0.003)*	5.97(0.015)*
Marine capture & coastal aquaculture	0.15*	0.01	0.07*	5.97(0.015)*	4.69(0.030)*	0.217(0.642)
Livestock	0.13*	−0.17*	0.01	1.11(0.292)	11.48(0.001)*	22.53(0.000)*
Hunting & others	−0.13*	0.00	0.29*	1.83(0.175)	0.00(1.000)	0.01(0.922)
Forestry	0.07*	−0.03	−0.07*	3.62(0.057)	10.87(0.001)*	0.73(0.393)

* Significant at $\alpha = 0.05$.

collecting grass, wood, bamboo, wild animals and plants for sale, on the other. Consequently, agriculture in JMA was classified overall into 10 types.

The 10 agricultural types were spatially clustered in different areas/villages as indicated by the PCA analysis (Fig. 9). The clusters indicate the proximity between different agricultural types. The first is upland horticulture, plantation, upland paddy & food crops, and forestry that share the same characteristic of land resources located in the mountainous area in the south. The second is marine fisheries and coastal aquaculture located close to the sea in the north. The third is lowland paddy and food crops, hunting & others, lowland horticulture, inland aquaculture, and livestock located in the central plane area and strongly influenced by urbanization. This last zone is mainly characterized by lowland horticulture, hunting &

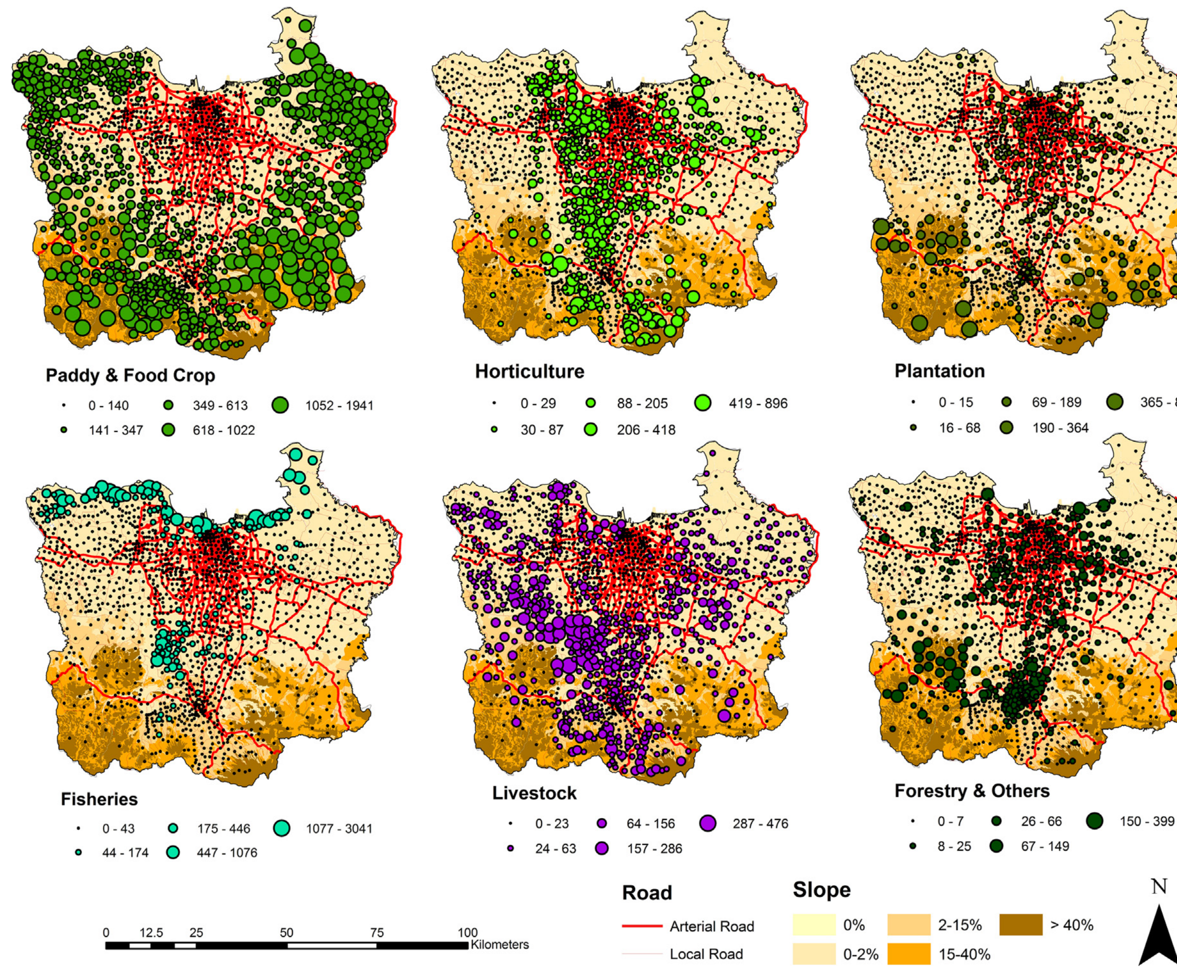

Fig. 8. Distribution number of farmers by farming type of each village in JMA.

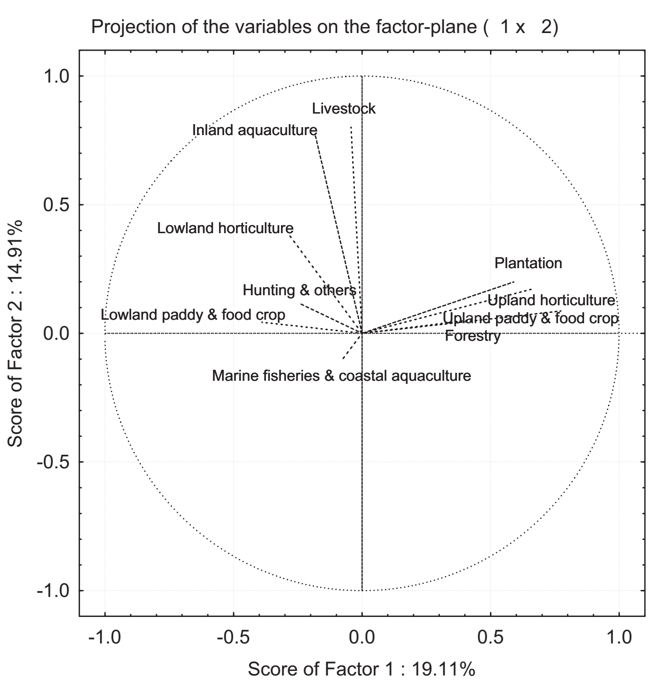

Fig. 9. Clustering of agricultural type as a result of PCA analysis.

others, and inland aquaculture, since livestock tended to approach the first cluster, and lowland paddy & food crops tended to approach the second cluster (see Fig. 9).

Further analysis of the correlations between farming types and variables comprising distance to arterial and local roads, population numbers, presence of rivers, irrigation, and lakes shows the following pattern (Table 2). Lowland horticulture, hunting & others, and inland aquaculture are located in proximity to the arterial roads in more populated areas. Lowland horticulture has shown to be the most stable type under urbanization because it does not depend on rivers, lakes, or irrigation, whereas inland aquaculture still needs to be close to irrigation or lakes. However, both of these agricultural activities were able to adapt and benefit from the development of the nearby urban market.

Lowland and upland paddy & food crops, upland horticulture, and livestock have developed in areas with low population density far from arterial roads but still close to local roads. Its presence also depends on the existence of rivers, lakes, or irrigation. Although these activities are threatened by urbanization, they can persist by shifting to more remote areas which, however, are still connected with the urban market.

Plantation, forestry, and marine fisheries & coastal aquaculture are located far from arterial roads. Except marine fisheries & coastal aquaculture, the other two agricultural types are located in more or less unpopulated areas. It is common in Indonesia that fishing villages have a dense population. All the activities are significantly correlated with the presence of rivers or irrigation.

From this analysis it can be concluded that agriculture types in JMA can be classified into three groups based on their response to urbanization. **The first category**, types that can adapt to and benefit from urbanization such as lowland horticulture and inland aquaculture. **The second category**, types that become vulnerable and must shift to the other places far from urbanized areas such as lowland and upland paddy & food crop, upland horticulture, and livestock. **The third category**, types that remain in place as long as they get sufficient environmental support such as plantation, forestry, and marine fisheries & coastal aquaculture.

4. Discussion and conclusions

For more than the last four decades, development in JMA has been characterized by strong urbanization. The urban area has expanded rapidly in all directions without successfully being controlled. Fortunately, land development in the water catchment area in the south has slowed down since the worst flooding in JMA in 2007 and the establishment of a new law for spatial planning. Land development permits within this area have been limited and some buildings which do not have a permit were even demolished. Despite these successes of planning to redirect urban expansion in JMA to the west and east of Jakarta, urban growth in the coming decades is predicted to follow the global trend of post-suburbia where industrial estates and new urban centers expand in the peri-urban zone and replace the desakota region (Hudalah and Firman, 2012).

This phenomenon should be of concern since the trend of urban growth in JMA was followed by declining population density. Urban mega-projects in the form of tall buildings, global business hubs, hotel and elite condominiums, shopping malls, resorts, and new towns with gated housing, have consumed excessive land in the peri-urban since the mid-1980s (Firman, 2009; Winarso, 2011; Douglass, 2013). Moreover, land speculation has led to excessive property investment that puts more pressure on the agricultural land in the peri-urban zone (Firman, 2009).

This situation has caused the large scale conversion of agricultural land and increased farmland fragmentation. Seventy-six percent of land use in JMA was classified as mixed land use in 2012 where most of the agricultural land was closely intermingled with urban land use. Consequently, conditions for farming have become increasingly difficult in the peri-urban zones, in particular for paddy rice-field farming which benefits from larger fields and more stable conditions for farming. Rahman and Rahman (2008) stated that a 1% increase in land fragmentation reduces rice output by 0.05% and efficiency by 0.03%.

It may therefore appear to be surprising that the proportionate cover of agricultural land only dropped by less than 10% of JMA's total surface area, although large tracts of farmland have been converted into urban land use. An explanation is that paddy fields and dryland agriculture were displaced by urbanization but mostly persisted by shifting to other areas in JMA. Consequently, large tracts of forest land in the mountainous area in the south of JMA have been lost and this increased environmental risk. Rustiadi et al. (2012) provided evidence of increased incidences of anthropogenic disasters in JMA, such as floods and landslides, in terms of frequency, intensity, and distribution which can be attributed to land use and land cover change.

While farming activities managed to persist overall in the peri-urban, their contribution to the peri-urban GDP continually decreased and ended up in a very small proportion. However, interestingly the relative contribution to GDP has remained stable after the economic crisis of 2007, as its development kept pace with that of other sectors in peri-urban JMA. This finding indicates that to some extent PUA has become connected to the urban economic system. Even more, GDP of the PUA which still increased, indicates that PUA has been able to compensate the declining agricultural land base through development of more profitable farming activities such as horticulture or inland aquaculture.

Simultaneously, the persistence of PUA has given opportunities to the farmers to survive and, surprisingly, even to increase in numbers. Even farmers from outside of JMA have entered the horticulture business (Siregar, 2006). Obviously, the growing market in JMA also supported the persistence of PUA. Therefore, many peri-urban dwellers are still involved in agricultural business within on-farm and off-farm activities. However, the increase of agricultural jobs occured mainly due to the growing number of landless farmers. Most farmers who lost their farms due to urbanization, do not have enough skills to get a job in the urban sector (Arai, 2011); thus, they still stay in the farming business as farm workers. Likely, these farm workers are particularly vulnerable to any future economic crisis.

The dynamics of PUA cannot be separated from a policy response to increasing food prices caused by the economic crisis in 1998 and 2007. In 1998, the governor of Jakarta introduced a policy to utilize vacant lands for agricultural development as a temporary solution to satisfy the food demands (Purnomohadi, 2001). Learning from the crisis, a government regulation about food security was introduced in 2002 to strengthen food production, equitable food distribution, and to stabilize food price. When the second crisis occured in 2007, a new law for spatial planning was established that mandates the development of so called agropolitans, i.e., agricultural towns in rural areas to facilitate the supply of agricultural products from rural to urban centers. Finally, in 2009 a law was enacted to protect agricultural land for food production, although the mechanism through which the land can be protected is still unclear. Unfortunately, these initiatives were not strongly supported since the time when the economic crisis came to an end. The PUA seems to have been regarded as a safety net in the emergency situation of the food crisis, but it is again neglected under "normal" situations.

PUA existence under urban expansion shows type-specific responses. Lowland horticulture has emerged as the most robust agricultural activity because it only requires small patches of land close to the urban area. Frequent harvesting and easy access to the market have given sufficient income to the farmers. Lowland horticulture usually uses the vacant land near the city such as the river banks, roadsides, areas near railways, and public or private lands which are not developed yet (Purnomohadi, 2001; Siregar, 2006). Therefore, proximity to the water resources does not become a constraint, although horticulture usually needs intensive watering. Commonly, the farmers build a non permanent house near their cultivated land and spend most of the time to work on intensive cultivation of horticultural produce (Siregar, 2006). They move to other areas when the land is used by the owner. Therefore, they permanently face the risk of insecure land property rights (Purnomohadi, 2001; Siregar, 2006). These activities are also supported by the situation where cool chain infrastructure is not well developed; thus, perishable horticulture is often produced close to the demand location (Midmore and Hansen, 2003; Dyck et al., 2012).

Inland aquaculture is similar to lowland horticulture as it is also a cash crop that can be practiced on small parcels of land. It produces ornamental fish and fresh fish for consumption, which need to be immediately transported to the market, whilst it does not generate too much waste that disturbs the neighborhood. In addition, the lowland area in the north part of JMA has many lakes and rivers that can be used to produce fish for consumption. Some areas in the south west (Bogor district) are well known as a production center of inland aquaculture since the 1980s (PSP3, 2010). Moreover, Bogor district also has the biggest market for ornamental fish in Indonesia with almost 1000 traders and transactions that reached 55,000 US$ a day in 2011 with the currency of 9000 IDR/US$ (Livestock and Fisheries Office of Bogor District, 2011).

On the other hand, paddy fields and food crops, including upland horticulture, have been pushed outwards by urbanization, as these types of agricultural land are owned by small farmers who receive insufficient benefits from their farmland. As Firman (2000) stated, selling the land on the fringe of Jakarta often gives more profit to the farmers than cultivating it for paddy fields. Livestock also moves away from the expanding settlements because of animal waste. Still, most of these activities are continued on land further away from the settlement.

The results of this study provide a better understanding of the interactions between urbanization and the PUA. PUA shows various responses to urbanization and the economic situation that are not only important for the peri-urban but also the entire urban system. On the one hand, PUA provides jobs and income for the farmer and peri-urban dwellers as well as increasing food security in times of crisis. On the other hand, the persistence of agricultural land has led to the conversion of forestland and increased environmental risks, in particular flooding. It is concluded that urban development scenarios which simply neglect the PUA do not only threaten the livelihood of the farmers and many peri-urban dwellers but also increase the vulnerability of the JMA to higher food prices and natural hazards.

Therefore, PUA needs to be adequately integrated into the planning and management of the urban system. Paül and McKenzie (2013) suggested the development of restricted agricultural zones that must be supported by various strategies to develop a connection between this agricultural zone and the urban system. However, providing a special zone for agriculture is not fully applicable in the peri-urban of JMA, which is characterized by a small mix of urban and rural land uses and a variety of agricultural types that respond differently to urbanization.

Policies for PUA need to be adjusted to the size, distribution, and dynamics of agricultural land in the peri-urban region as well as to the capacity of each agricultural type to adapt to urbanization. This may, in particular, be achieved by developing agricultural types, such as lowland horticulture and inland aquaculture, on the small and fragmented agricultural land near the urban zones. However, some issues related to pest management and utilization of pesticides in horticulture should be considered to maintain the quality of the urban environment. On the other hand, larger tracts of agricultural land far from urbanized areas can be maintained by allocating special zones as suggested by Paül and McKenzie (2013) particularly to control the shift of paddy field, food crops, upland horticulture, and livestock, as well as manage these agricultural zones efficiently and sustainably. Both strategies should be supported by a policy approach that helps to secure the land for agricultural production, particularly for the landless farmers.

Still, further strategies are required to develop a connection between the PUA and the urban system. Instead of merely focussing on development of food networks as suggested by Paül and McKenzie (2013), this connection should simultaneously address various urban development issues including food production, poverty alleviation, creating jobs, generating income, and improving environmental conditions. As suggested by Zasada (2011), the success of PUA management will depend on the capacity to develop its multifunctionality in the urban system; however, this multifunctionality needs to be further assessed to define the different functions of PUA in different zones of the peri-urban.

This research was based on the analysis of multiple spatial and statistical databases. Combining land use change analysis with multivariate statistical approaches on time series databases can give a broader perspective about the PUA dynamics and the response of different types of PUA to urbanization. While the phenomenon of the desakota region has been increasingly covered by scholars (McGee, 1991, 2010; Yokohari et al., 2000; Moench and Gwayali, 2008Douglass, 1998; Douglass, 2013), there is still a lack of knowledge on its dynamics and functional roles based on in-depth empirical study.

The results from this study thus contributed to an improved conceptual understanding of the desakota region and its potential role for urban sustainability by particularly highlighting the specific response and functions of PUA. Distinction of PUA types and exploring their different capability to adapt to urbanization, to support the livelihoods of peri-urban dwellers, and to increase urban resilience to higher food price and environmental hazards adds to further development of the theory of desakota as suggested by Moench and Gyawali (2008), and McGee (2010).

It is concluded that development of a multifunctional PUA could become a key to manage desakota region as well as support urban sustainability. However, further study is needed to explore the multi-functionality of the PUA to deal with specific urban development issues in different areas of JMA. Furthermore, in depth study of farmer's adaptation to urbanization is required by adopting a micro-scale approach at village and farm levels to better understand the mechanisms behind the dynamics described in this paper.

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Paper II

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Peri-urban agriculture in Jabodetabek Metropolitan Area and its relationship with the urban socioeconomic system

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ABSTRACT

Peri-urban agriculture (PUA) has been proposed as an important urban element to deal with the challenges of increasing poverty, food insecurity, and environmental degradation as particularly found in rapidly expanding cities of the developing world. However, farming in the peri-urban is under strong pressure from urbanization. The economic and social roles of farming need to be better understood in order to integrate peri-urban agriculture into urban planning. This study used multivariate techniques and Geographically Weighted Regression to analyze statistical data at a village and sub-district, to explore the varying relationships between agricultural activities and urban economic activities, urban poverty and informality, as well as food security. This method was applied in the Jabodetabek Metropolitan Area (JMA) with Indonesia's capital Jakarta at its core, and it resulted in some important findings. **First**, PUA was more associated with the increasing low and middle class residential areas and the growing small-middle scale urban economic activities rather than development of tourism and larger traditional market facilities. **Second**, whereas PUA in the North of JMA was under pressure by the increasing poverty, in the Southeast of JMA it has expanded concurrently with increasing poverty. **Third**, PUA is strengthened by increasing informal activities in the peri-urban zone that offer alternative jobs and additional income for the farmers. **Fourth**, PUA in the surroundings of Jakarta as well as in the East and Northeast of JMA has contributed to increasing food affordability as well as strengthening food security policy. Based on these results, recommendations to maintain the PUA have been formulated to support its role for the peri-urban economy, reduce poverty, manage informality, and increase food security.

1. Introduction

Asia, as other parts of the world is experiencing rapid urbanization. A particular phenomenon is the emergence of megacities as regions which have 10 million inhabitants or more (Dahiya, 2012; Swerts and Denis, 2015). Until 2030 it is expected that globally the number of megacities will increase from presently 28 to 41 and half of these will be located in Asia to accommodate 651 million inhabitants (UNDESA, 2014). Rapid expansion of urban areas in Asia causes large scale conversion of agricultural land which is further exacerbated by urban growth at declining population densities. In the peri-urban zone, urban and rural land uses have closely intermingled and led to the so called "desakota" phenomenon (McGee, 1991).

It has been suggested that desakota areas can play an important role in sustainable development of urban regions which are facing issues of poverty, food insecurity and environmental degradation (McGee 2010; Douglass 2013). It becomes a crucial zone to produce food for the urban population who is often living under precarious conditions and is vulnerable to the volatility of gas and food prices in the global market. Moreover, it can provide jobs and income for the poor, as well as regulating ecosystem services to reduce urban vulnerability to environmental hazards and enhance climate change adaptation (Yokohari et al., 2000; Moench and Gyawali, 2008; Pelling and Mustafa, 2010; McGee 2009, 2010). However, managing the complex urban-rural structure is particularly challenging, especially to preserve small and segmented agricultural land in the desakota region.

A concept of urban agriculture or "Intra and Peri-urban Agriculture" has been adopted widely since it was endorsed by UN agencies such as UNDP and FAO in 1996 (Mougeot, 2000). This idea offers an alternative action to cope with the needs for food, jobs, and achieving sustainable development in the cities (UNDP, 1996; FAO,

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1999). Peri-urban agriculture (henceforth called PUA) is expected to provide multiple functions that benefit the urban system (Yang et al., 2010; Zasada, 2011). This concept may promote integration of urban agriculture into urban development (Zasada, 2011; Aubry et al., 2012; Indraprahasta 2013).

However, the mechanisms by which farmland in the peri-urban can be effectively preserved are poorly understood (Paül and McKenzie, 2013). In particular, there is still a lack of understanding of: (1) farming types diversity in peri-urban areas and how they respond differentially to urbanization (2) the potential of these farming types to provide multiple functions and on which factors the provision of these functions depends, and (3) suitable policies that not only preserve the farmland but also promote the different functions of the PUA. In a previous research, Pribadi and Pauleit (2015) found that some farming types in the peri-urban area benefit from urban expansion while others were pressured by urban expansion. The study indicated that there are various interactions between PUA and urban development that need to be better understood to promote the PUA including develop its multifunctionality in the urban system.

The crucial question is how to decide which, where, for what reasons, and how the PUA should be preserved or developed (Aubry et al., 2012). Since multifunctionality is considered a key to preserving the PUA, it is important to define which PUA activities are able to provide several functions, have less or no function, or are even harmful to urban areas.

A number of studies have been conducted to deal with that question. Commonly, they used a land evaluation method based on a set of multi-criteria built in GIS to define agricultural zones that should be preserved in the peri-urban area (Thapa and Murayama, 2008; Tassinari et al., 2013; Russo et al., 2014). Representatives of farmers, local authorities, and experts were involved in the development of the criteria. Yet, this approach was more focused on land suitability assessment than aiming to understand properly the relationships between PUA and the urban system.

Aubry et al. (2012), on the other hand, presented a multidisciplinary approach based on farm surveys and collaboration between several experts to assess the diversity, location, and functions of PUA in providing food and maintaining the environment. This method offered a broader perspective in PUA in supporting urban planning policy because the characteristics and the spatial distribution of farming activities as well as their role in the food supply and urban environment could be clearly identified. Unfortunately, this study was based on only a small number of surveys, thus the statistical representativeness of the study was limited (Aubry et al., 2012). In fact, there is further demand for robust empirical evidence to allow for public policy support for PUA (Zezza and Tasciotti, 2010).

Our study aims to analyze the socioeconomic roles of PUA in different areas of the peri-urban zone of Jabodetabek Metropolitan Area (JMA) based on a statistical approach to produce strong empirical evidence. JMA is one of the largest and fastest growing megacities in Asia, which is facing serious socioeconomic challenges with increasing poverty and food insecurity (Rustiadi et al., 2015). Problems have been exacerbated by the pressures of urbanization on rural economies in the desakota system (Pelling and Mustafa, 2010). Within this situation, informal activities have emerged as a response of the poor to their economic vulnerability (Moench and Gyawali, 2008).

Pribadi and Pauleit (2015) showed that PUA in JMA still dominates peri-urban land use and supports the livelihood of many peri-urban dwellers. Despite the strong pressure from rapid urbanization for almost three decades, overall PUA land use in JMA has not strongly declined, but compensated most of its losses to urban via conversion of woodlands. Moreover, the problems of food insecurity due to the global economic crisis that hit JMA in 1998 and 2007 supported PUA. However, PUA types have been differentially affected by urbanization. Lowland horticulture and inland aquaculture benefited from the proximity of markets. Paddy fields and food crops, on the other hand, suffered from fragmentation into smaller patches and overall declined. The latter shows that integration of PUA land in urban planning is still problematic as its functions are not sufficiently recognized (Hudalah and Firman 2012; Indraprahasta 2013). Therefore, this paper aims to analyze the different roles of PUA in different areas of peri-urban JMA based on its relationship with (1) urban economic activities, (2) urban poverty and informality, and (3) food security, in order to enhance its integration in urban planning policy.

2. Materials and methods

2.1. Research area

Jabodetabek is an acronym for Jakarta, Bogor, Depok, Tangerang, and Bekasi. This area covers Jakarta as the capital city which is surrounded by 5 municipalities and 3 districts of Bogor, Depok, Tangerang, and Bekasi (Fig. 1). The Northern part of JMA consists of lowland area which stretches from the shores of the sea to approximately 40 km inland. The Southern part of JMA consists of a mountainous area which is mostly important as a water catchment area. In 2010, the total population of JMA reached 27.96 million within an area of 6256 km^2, corresponding to a population density of 4469 inhabitants/km^2 (Rustiadi et al., 2012).

In 2011, this area encompassed 183 subdistricts and 1495 villages. A village is the smallest spatial unit of government with a range from less than 100 to more than 500 ha, while each subdistrict consist of more or less 8 villages. This research used village and subdistrict as a spatial unit for analysis. The peri-urban area was defined as villages or subdistricts in Jakarta which are located near to the border of Jakarta plus villages or subdistricts in Bogor, Depok, Tangerang, and Bekasi.

2.2. Analysis of relationships between PUA and urban economic activities

Data derived from Village Potency Data (PODES) in 2006 and 2011 published by the Central Statistic Agency (BPS) was used for statistical analysis. We assumed that urban economic activities can be represented by increasing settlement, industry, and services, thus variables which were used as a proxy consisted of the number of households, hotels, villas, restaurants, permanent and non permanent traditional markets, small scale industries, mini-markets, food-stalls, and stalls in each village. As noted, a traditional market refers to a market which is characterized by the presence of many sellers and buyers who daily trade based on negotiable price and it is different from the modern market. On the other hand, the number of farmer households by village was used as a proxy for the PUA. The difference of these variables in each village from 2006 to 2011 was calculated and classified into “1” representing increasing value, and “0” representing constant or decreasing value. The years 2006 and 2011 were chosen since the GDP (Gross Domestic Product) of PUA in JMA had constantly increased within this period (Pribadi and Pauleit, 2015). Correspondence analysis (CA) in STATISTICA software (StatSoft Inc., 2007) was used to analyze the association among variables.

CA is an exploratory technique to analyze simple two ways and multiple-way tables containing some measures of correspondence between the rows and columns. CA is well suited to measure the association between variables based on the binary data. Each variable will have scores in a row and column, thus they can be plotted on two independent axes. The proximity between variables within

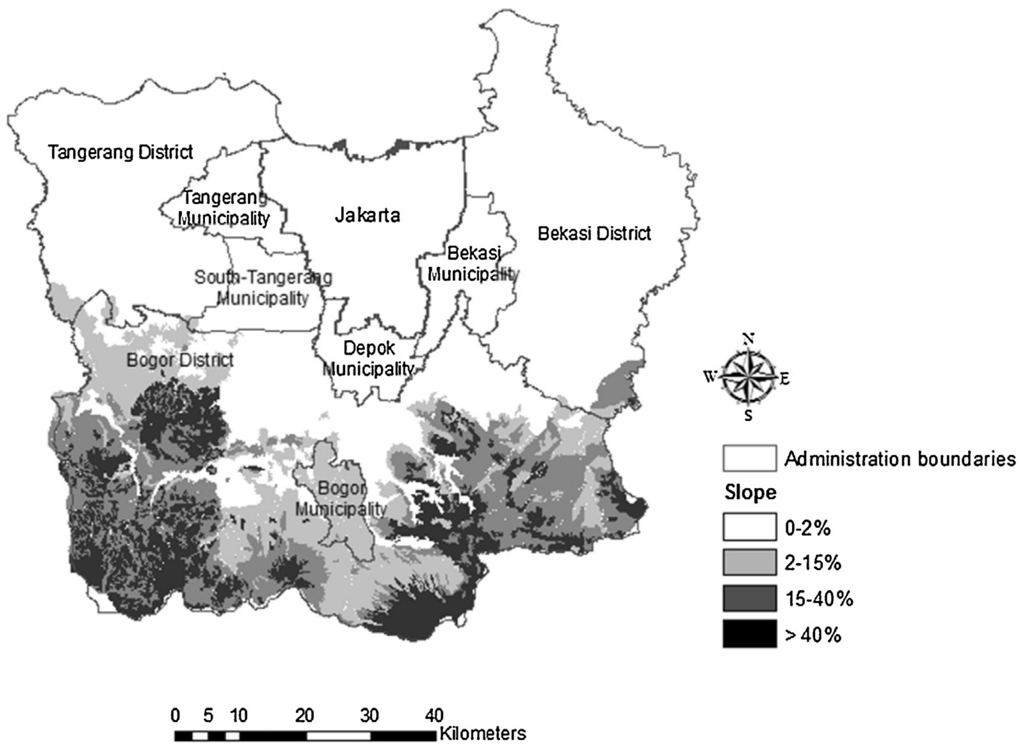


Fig. 1. Map of Jabodetabek Metropolitan Area.

the graph describes the level of association between variables. In this study, we want to identify what kind of urban economic activities that were closely associated with the increasing PUA farmers.

2.3. Analysis of the relationships between PUA and urban poverty, informality, and food security

PUA takes different forms and it may have other functions in different parts of the peri-urban (Pribadi and Pauleit, 2015). Therefore, the relationship between PUA and urban development issues is likely varied across the peri-urban landscape. We were interested in the relationships between PUA and the three issues of urban poverty, urban informality, and food security.

As a further method, Geographically Weighted Regression (GWR) was applied to analyze the varying relationship between variables across the different parts of the study area. The technique allows to conduct local regressions that contain local parameter estimates as disaggregation of the ordinary/global regression that contain global parameter estimates. It is applied when the measurement of a relationship depends on the location where the measurement is taken (Fotheringham et al., 2002).

GWR has been introduced in the spatial econometric literature by McMillen (1996), McMillen and McDonald (1997), and Brundson et al., 1996. Now, GWR has been widely applied in urban planning and development, such as studying urban land use change (Gao and Li, 2011; Su et al., 2012), urban heat island and natural amenities (Szymanowski and Kryza, 2011; Nilsson, 2014), variation in house prices (Bitter et al., 2006; Huang et al., 2010), and urban and regional development (Yu, 2006). However, GWR has not been employed to analyze the PUA.

The general equation of GWR model can be written as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{n} \beta_k(u_i, v_i) x_{i,k} + \varepsilon_i$$

where y_i is independent variable at the location i; $\beta_0(u_i,v_i)$ is the intercept coefficient at the location i; $x_{i,k}$ is the kth explanatory variables at the location i; $\beta_k(u_i,v_i)$ is the local regression coefficient for kth explanatory variables at the location i. Moreover (u_i,y_i) are Cartesian x and y point coordinates, normally referring to the centroid of the spatial unit for analysis. Coefficient values in the equation were calculated by using the following formula:

$$\hat{\beta}(u_i, v_i) = \left(X'W(u_i, y_i)X\right)^{-1} X'W(u_i, y_i)y$$

where $\hat{\beta}(u_i, v_i)$ is the estimate of coefficient values at the location i, while $W(u_i,y_i)$ is a n by n spatial weighting matrix for n number of location i. The weight is valued based on the proximity of the regression point i to the data points around i, considered as a function of distance between points. The decreasing weight of a point along with increasing distance to the other points follows the Gaussian curve (Fotheringham et al., 2002).

This research used the adaptive bi-square function to determine the Gaussian curve, so that the number of neighbors is kept constant. It is usually used when the study area covers spatial units for analysis which have different densities. As we used sub-district as a spatial unit for analysis in the model, a different density of subdistrict is found in JMA. The adaptive bi-square function is:

$$W_{ij} = \begin{cases} \left(1 - d_{ij}^2\right)^2 d_{ij} < \theta_{i(k)} \\ 0 d_{ij} > \theta_{i(k)} \end{cases}$$

where W_{ij} is the weight value of observation at location j to estimate coefficients at location i, d_{ij} is the Euclidian distance between i and j, $\theta_{i(k)}$ is an adaptive bandwidth size defined as the kth nearest neighbor distance. The optimal bandwidth size was determined by the method of golden section search where all alternative models with different bandwidth were evaluated to obtain the minimum value of AIC (Akaike Information Criterion) as an indicator of the best fit model.

Two GWR models were developed in this research to represent the relationships between (1) PUA and urban poverty and informality, and (2) PUA and food security. The data used in the model encompass individual and household data obtained from Population Census 2010 (Sensus Penduduk 2010) and the National Social-Economic Survey 2010 (Susenas 2010) published by BPS, and poverty data 2011 published by National Task Forces for Poverty Alleviation (Tim Nasional Percepatan Penanggulangan Kemiskinan-TNP2K). While the poverty data is not from the same year as the other data sets, this was not considered a problem as the change of numbers from one year to the other is small. Selected variables from these databases were presented on sub-districts level, thus the GWR model was applied to produce local parameter estimates of each subdistrict. The GWR model was calculated by using ArcGis 9.3 and GWR 4 software developed by Nakaya et al. (2009).

In the first model, the ratio of farmers on total workers was used as the dependent variable (*R_f*). Explanatory variables comprised: (1) ratio of poor people on total population (*R_p*); (2) ratio of almost poor people on total population (*R_ap*); (3) ratio of self-employed on total workers (*R_se*); (4) ratio of free-worker on total workers (*R_fw*), and (5) ratio of non-paid worker on total workers (*R_npw*). The first two variables represent urban poverty, while the remaining variables represent urban informality. The equation for the model can be expressed as follows:

$$R\_f_i = \beta_{i0} + \beta_{i1} \times \mathrm{R\_p_i} + \beta_{i2} \times \mathrm{R\_ap_i} + \beta_{i3} \times \mathrm{R\_se_i} + \beta_{i4} \times \mathrm{R\_fw_i} + \beta_{i5} \times \mathrm{R\_npw_i}$$

where the coefficient β_{*j} (j = 0,1,2,3,4,5) varies in respect to the sub-district i.

In the population census, poor people were defined as inhabitants that have income below the poverty line, while almost poor people were defined as inhabitants that have income slightly above the poverty line. Both are classified as vulnerable group to poverty (TNP2K, 2012). The poverty line is 233,740 IDR/capita/month equivalent to 25 USD/capita/month published by BPS in 2011. Furthermore, self-employed were defined as people who have their own business or offer particular skills such as tailors, carpenters, builders, barbers, etc.; free-workers were defined as people who do not have a permanent job; and non-paid workers were defined as people who work in the family business without any payment.

In the second model, some of the variables were based on household data, which was standardized by the number of household members. Therefore, we obtained a similar size of households with four members as an average value. Afterwards, the average amount of money spent by a household to buy staple food per month (IDR/month) was used as a dependent variable (*Fe*). The staple food includes rice, fish, meat, eggs, milk, vegetables, fruits, cooking oil, drink (coffee, tea, etc.), and spices, and they were consumed in a relatively similar amount per household. According to Government Regulation number 68/2002, food affordability becomes the most important indicator of the succesful food security policy, therefore this dependent variable was used as a proxy for food security. Furthermore, the explanatory variables comprised: (1) the average total expenses of a household per month (*Te*), (2) the ratio of average food expenses on average total expenses of a household per month (*R_fe*), and (3) the ratio of farmers on total workers (*R_f*). The total expenses can represent the total income of a household, whereas the ratio of food expenses on total expenses can represent a household capacity to deal with food price fluctuation as the amount of staple food consumption per household is relatively stable. Then, the equation of the model can be expressed as follows:

$$Fe_i = \beta_{i0} + \beta_{i1} \times \mathrm{Te_i} + \beta_{i2} \times \mathrm{R\_fe_i} + \beta_{i3} \times \mathrm{R\_f_i}$$

where the coefficient β_{*j} (j = 0,1,2,3,4,5) varies in respect to the sub-district i.

All parameter estimates of both models which were significant based on a t-test with α = 0.05 were mapped to describe varying relationships across sub-districts in JMA. Afterwards, the PUA type in significant sub-districts were identified based on the number of farmer types. There are 10 farmer types of PUA in JMA consisting: (1) lowland paddy and food crops, (2) upland paddy and food crops, (3) lowland horticulture, (4) upland horticulture, (5) plantation, (6) inland aquaculture, (7) marine fisheries and coastal aquaculture, (8) livestock, (9) forestry, and (10) hunting and others (Pribadi and Pauleit, 2015). It will provide valuable information about the PUA type that should be of concern in every sub-district which has a significant coefficient of the GWR model.

3. Results

3.1. Relationship between PUA and urban economic activities

Despite continuing urban expansion in JMA, Fig. 2a shows villages that still have an increasing number of farmers from 2006 to 2011. Some villages tended to be clustered in the South of JMA but most of them are distributed sparsely in the peri-urban area and mixed up with urban activities. The increasing number of farmers was mostly associated with the increasing number of households, stalls, food stalls, small scale industries, and mini-markets (Fig. 2b) but only weakly associated with the increasing number of hotels, villas, restaurants, and permanent and non-permanent traditional markets.

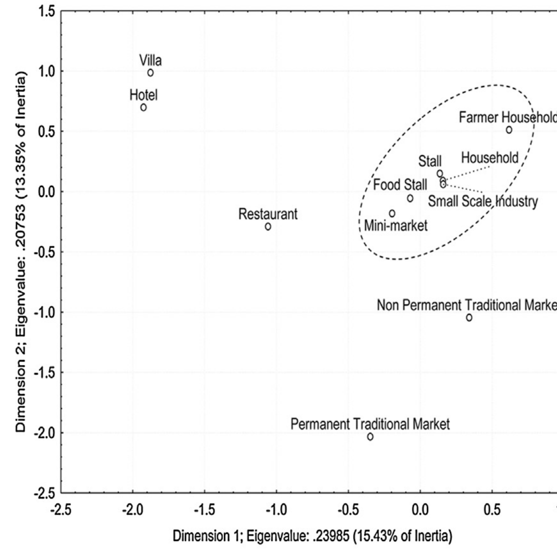
The increasing number of PUA farmers showed a stronger correlation with the increasing small-middle sized urban economic activities such as smaller industries, stalls, and food stalls. It was also related to the mushrooming low and middle class residential areas in the peri-urban zone described by an increasing number of households and mini-markets. Low cost housing has been widely developed in the peri-urban zone of JMA due to increasing demand of inhabitants and subsidies from the government (Jakarta Globe, 2013). Furthermore, mini-markets were usually built concurrently with new low and middle class residential areas. Surprisingly, the increasing number of PUA farmers had only a weak association with the developing tourism and traditional market facilities. Both facilities are developed to serve urban demand for recreational activities and food product, and commonly are regarded to have a close link with the PUA.

3.2. Relationship between PUA and urban poverty and informality

The relationship between PUA and urban poverty and informality encompasses complicated interactions between the varying character of PUA, types of poverty, and a variety of informal jobs across JMA. The GWR model showed better performance than the global regression. The GWR model produced a smaller AIC value (−705.43) than the global regression model (−608.63) and provided higher value of R^2 and adjusted R^2 (0.96 and 0.95) than the global regression model (0.89 and 0.88). Furthermore, the ANOVA revealed that GWR model significantly improved the performance of global regression model (Table 1).

In order to clarify the results, significant parameter estimates of this model were divided in two groups of independent variables. First, variables of urban poverty consist of *R_p* (poor people) and *R_ap* (almost poor people). Second, variables of urban informal-

(a)

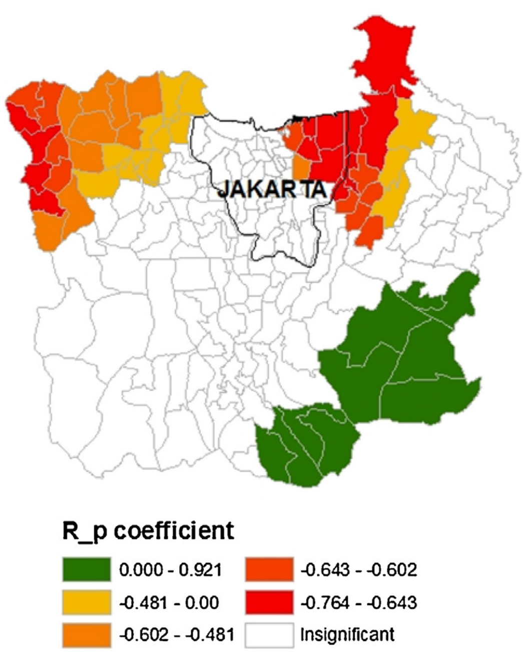


(b)

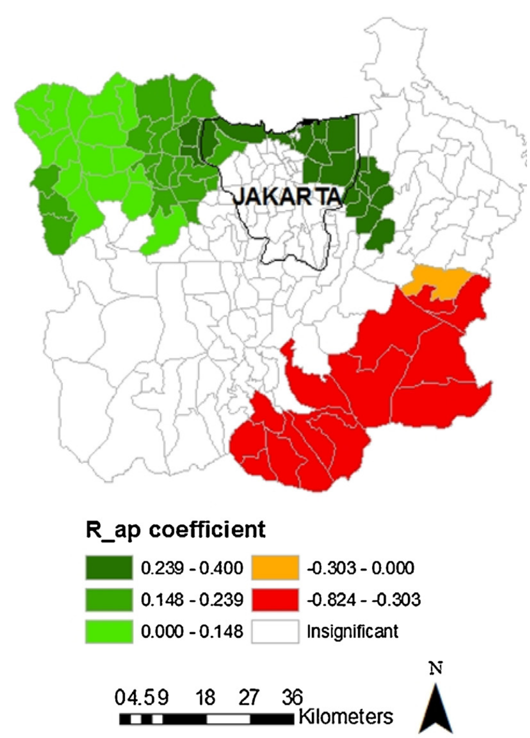
Fig. 2. (a) Villages that experience an increasing number of farmers from 2006 to 2011 (grey area); (b) The association between variables in a correspondence analysis.

Table 1
GWR Anova of Relationship Model between PUA and Urban Poverty and Informality.

Source	Sum of Square	Degree of Freedom	Mean Square	F-value	p-value
Global Residuals	0.355	6.000			
GWR Improvement	0.241	51.356	0.005		
GWR Residuals	0.114	125.6 44	0.001	5.150263	0.000000



(a)



(b)

Fig. 3. Map of significant coefficient of *R_p* (poor group) and *R_ap* (almost poor group) based on *t*-test at α = 0.05.
Note: the green color shows the positive sign, while the red color shows the negative sign.

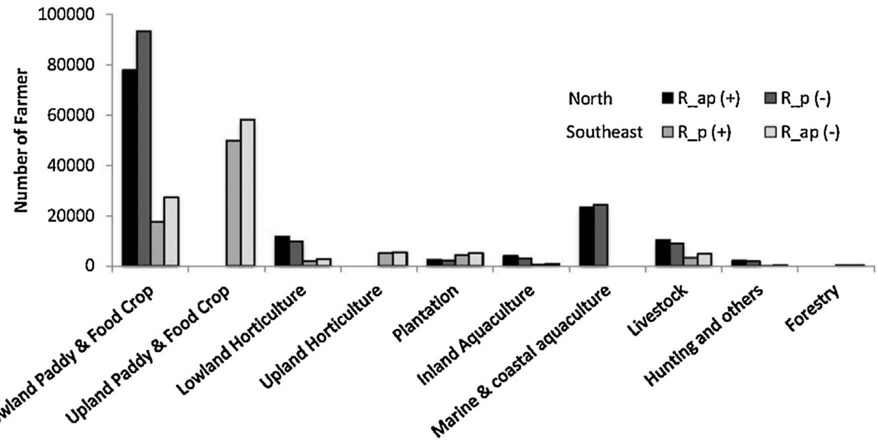


Fig. 4. Distribution of PUA types in zones of significant *R_p* (poor group) and *R_ap* (almost poor group) coefficients.

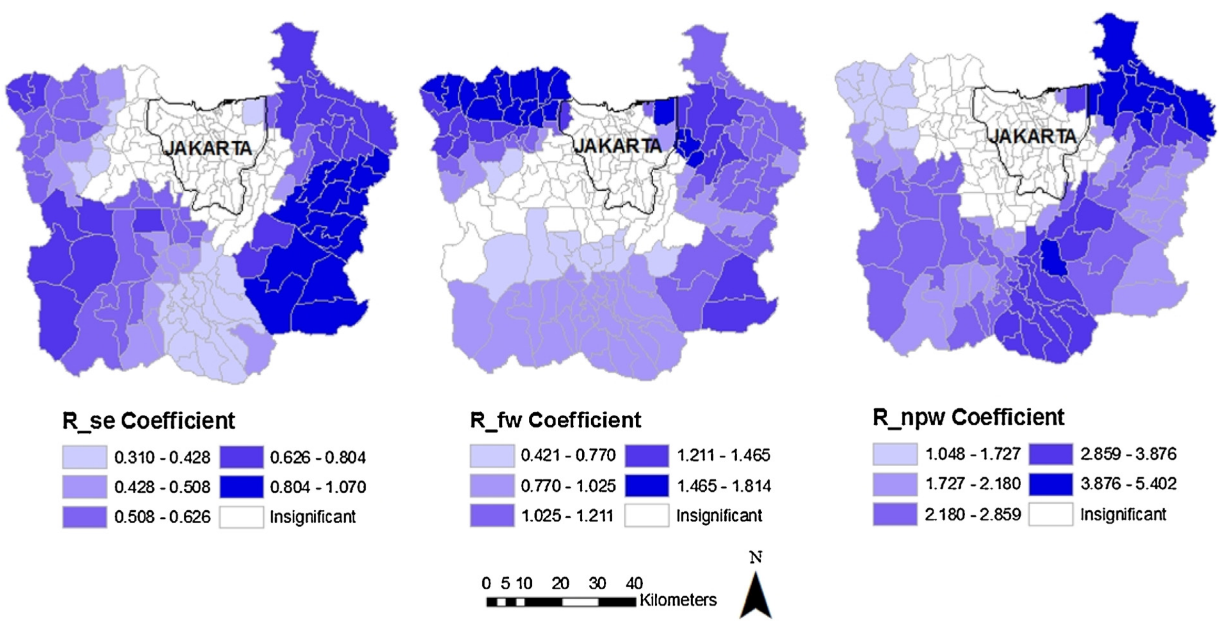


Fig. 5. Map of significant coefficient of *R_se* (self-employed), *R_fw* (free workers), and *R_npw* (non-paid workers) based on *t*-test at α = 0.05.

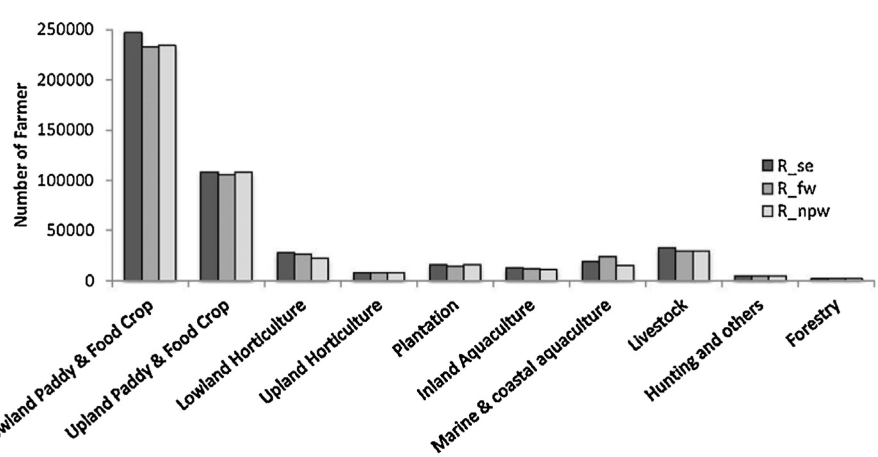


Fig. 6. Distribution of PUA types in zones of significant *R_se* (self-employed), *R_fw* (free workers), and *R_npw* (non-paid workers) coefficients.

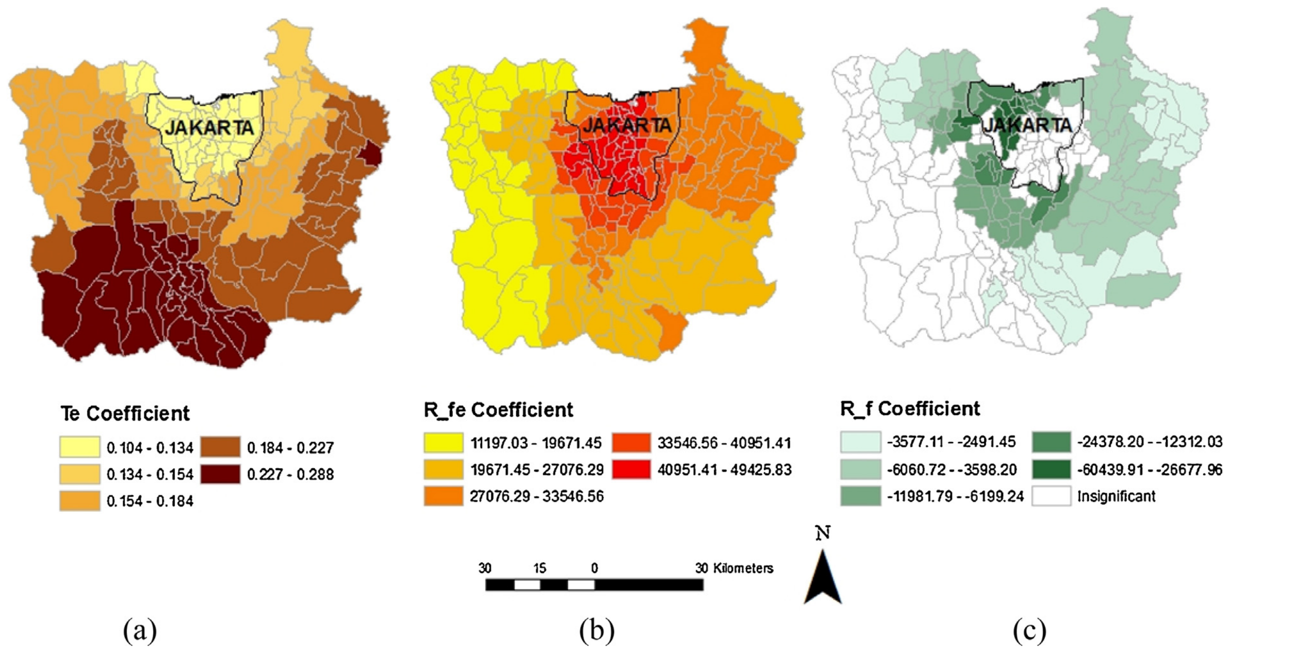


Fig. 7. Map of significant coefficient of *R_se* (self-employed), *R_fw* (free workers) and *R_npw* (non-paid workers) based on *t*-test at $\alpha = 0.05$.

ity consist of *R_se* (self-employed), *R_fw* (free workers), and *R_npw* (non-paid workers).

Areas where coefficient of *R_p* (poor people) and *R_ap* (almost poor people) were significant are presented in Fig. 3a and b. An increasing number of poor people were accompanied by increasing numbers of farmers in the Southeast (*R_p* positive), and decreasing numbers of farmers in the North (*R_p* negative) (Fig. 3a). Interestingly, an increasing number of almost poor people were related to an increasing number of farmers in the North (*R_ap* positive), and a decreasing number of farmers in the Southeast (*R_ap* negative) (Fig. 3b). This indicates that the fluctuation of poverty numbers in those two areas has a different impact on farming activities.

Fig. 4 shows the PUA types which were found in every zone with significant *R_p* (poor group) and *R_ap* (almost poor group) coefficients. PUA in the North, which has *R_p* negative and *R_ap* positive coefficients, was dominated by lowland paddy and food crop, lowland horticulture, marine & coastal horticulture, and livestock, whereas PUA in the Southeast, which has *R_p* positive and *R_ap* negative coefficients, was dominated by upland paddy and food crop, lowland paddy and food crop, upland horticulture, and plantation. PUA types in the North are more capital intensive than PUA types in the Southeast. Lowland paddy and food crops are mostly irrigated land. Lowland horticulture needs intensive production input and labor, marine and coastal aquaculture needs equipments, labor, fuel, etc., and livestock needs livestock breeds, cage, vaccines, etc. On the other hand, farmland in the Southeast was dominated by rainfed paddy fields on the upland that generally require less capital and make less profit.

The distribution map of significant *R_se* (self-employed), *R_fw* (free workers), and *R_npw* (non-paid workers) coefficients can be seen in Fig. 5. It reveals that an increase in all types of informal workers was accompanied by an increasing number of farmers. It is also found, that this only occurred in the peri-urban area.

Fig. 6 shows the distribution of PUA types in the areas with significant *R_se* (self-employed), *R_fw* (free workers), and *R_npw* (non-paid workers) coefficients. Lowland and upland paddy and food crops were relatively dominant in all of these areas. Both PUA types are labor intensive agricultural activities and produce low income.

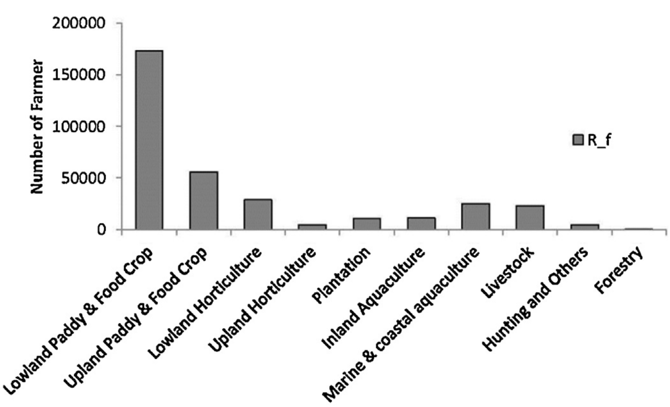


Fig. 8. Distribution of PUA type in zones of significant *R_f* (ratio of farmers) coefficient.

3.3. Relationship between PUA and food security

Not all types of PUA can supply food for the urbanizing population. Therefore, PUA that actually has a potential to support urban food security needs to be identified. The GWR model that describes the relationships between PUA and food security had better performance than the global regression model (AIC values of 4506.12 and 4697.07, respectively). Additionally, the GWR model had higher R^2 and adjusted R^2 values (0.91 and 0.89) than the global regression model (0.64 and 0.62). Based on Anova analysis, Table 2 shows that the GWR model significantly improved the global model.

The GWR model resulted in significant coefficients of *Te* (total expenses), *R_fe* (ratio of food expenses on total expenses), and *R_f* (ratio of farmers). Fig. 7a and b shows that the effects of *Te* (total expenses) and *R_fe* (ratio of food expenses on total expenses) were significant in all sub-districts of JMA but with different intensity. As mentioned in the methodology, *Te* (total expenses) can represent total income, while *R_fe* (ratio of food expenses on total expenses) can represent the effect of food price fluctuation. Based on both figures, the southwest area of JMA had higher *Te* (total expenses) coefficients and lower *R_fe* (ratio of food expenses on total expenses) coefficients. Results indicated that the food

Table 2
GWR Anova of Relationship Model between PUA and Food Security.

Source	Sum of Square	Degree of Freedom	Mean Square	F-value	p-value
Global Residuals	2,141,371,734,594.42	4.000			
GWR Improvement	1,648,317,533,016.36	38.886	42,387,947,957.36		
GWR Residuals	493,054,201,578.07	137.114	3,595,955,776.54	11.787672	0.000000

expenses in this area were more influenced by total expenses (total income) than food price fluctuation. On the other hand, the urban core (Jakarta) had a lower *Te* (total expenses) coefficient and a higher *R_fe* (ratio of food expenses on total expenses) coefficient. It indicated that the food expenses in this area were more influenced by food price than total expenses (total income).

R_f (ratio of farmers) was the only variable that had a negative coefficient, thus it contributed to reducing food expenses (Fig. 7c). However, it did not occur in all areas of JMA. The effect was significant mainly in the surroundings of Jakarta as the urban core, East, and Northeast of JMA.

Fig. 8 shows the PUA types which were found in the area of significant *R_f* (ratio of farmers) coefficients. PUA was dominated by lowland and upland paddy and food crops, lowland horticulture, marine & coastal aquaculture, livestock, and small number of farmers in other activities. The five dominant PUA types in this area produce staple food which is needed for daily consumption of urban and peri-urban dwellers.

4. Discussion and conclusion

The results of our study provide new insights into the role of PUA in JMA. The lack of PUA connectivity with the formal sectors has covered up its importance in the urban economy. The expansion of hotels, villas, restaurants, and even traditional markets was less associated with the increasing number of farmers in the peri-urban. It is contrary to the presumption that developing agro-eco-tourism activities or building traditional markets will automatically strengthen the existence of the PUA. For instance, in Puncak, the most favorite tourism area in peri-urban of JMA, most of hotels, villas, and restaurants were designed to attract urban visitors enjoying the natural amenities of agricultural landscapes, while there are no economic benefits for the farmers (Konsorsium Penyelamatan Kawasan Puncak, 2014).

Furthermore, there is less connectivity between PUA and the nearby traditional markets (see also Tsuchiya et al., 2015). This confirms a study by Eliyani (2010) who found that agricultural products in traditional markets in Bogor, a region which has the largest amount of agricultural land in JMA, were mainly supplied by wholesale markets in Jakarta. The wholesale markets collect products from outside JMA and distribute them to all areas within JMA (Government of DKI Jakarta Province, 2009; Mahardika, 2013). Apparently, the development of traditional markets is more intended to serve urban consumers instead of providing market places for local farmers.

However, the number of PUA farmers is increasing in parallel with the expanding low-middle class residential areas and small-middle scale economic activities. Low-cost housing development contributes to agricultural land conversion, but it also stimulates increasing various demands of the residents for local products, especially food. Development of minimarkets as well as increasing numbers of food street vendors and food peddlers was usually found close to the low and middle class residential areas. Furthermore, the number of stalls, food stalls, and small food and beverage industries also increased, and there is a growing market for products from agricultural material such as wood industry for furniture, leather industry for shoes, sandals, belt, bag, wallet, etc. and weaving industry.

In addition, due to the predominantly small size of their farms, farmers prefer to farm near the settlements for better access to middlemen, petty traders, or consumers. Farmers prefer to sell bigger harvests on-site to a middleman to reduce transportation cost, whereas small harvests and crops that are harvested several times during the year (eg. horticulture) are directly sold to the consumers or petty traders. This market pattern is common for various commodities in JMA (see Sihombing, 2010; Ariyanto, 2008; Yenni, 2007; Silalahi, 2009; Widiyanti, 2008; Hutabarat, 2012).

Most of small-middle sized economic activities are considered as informal economic activities. The results from GWR analysis has clearly indicated that development of informal jobs in the peri-urban has promoted PUA. Three types of informal works comprising self-employed, free workers, and non-paid workers are able to support the livelihood of the farmer that mainly work on lowland and upland paddy and food crops. Hence, these PUA types still persist despite low economic benefits.

Farmers are able to earn more income, either as self-employed or free workers such as small traders, porter, gardener, pedicab drivers, construction laborers, etc. by using the spare time between harvest and the planting season. Moreover, increasing numbers of small traders can develop markets for agricultural products as well. Increasing numbers of free workers and non-paid workers from the family members also provide more available labor for agricultural activities. Therefore, growing informal economic and informal jobs support the capability of farmers to preserve their farming activities.

Still, most of the PUA farmers live in poverty. In the Southeast of JMA, increasing poverty lead to an increasing proportion of farmers. PUA types which are dominated by upland paddy and food crops do not need too much input and use family labor, thus the capital needs are relatively small. Furthermore, lack of the government's control over forest land in this area has led to its conversion into farmland. As a result, the poor people living in this area can simply go into the farming activities to get income or food stock for their daily consumption. However, the farmers prefer to leave their agricultural activities when they have more money.

On the other hand, PUA in the Northern part of the region, which is dominated by capital intensive agriculture types such as lowland/irrigated paddy and food crops, lowland horticulture, marine & coastal horticulture, and livestock, can offer a better income, but needs high quality input to reach optimal productivity. PUA in this area has been developed on fertile soils and it has a more developed agricultural infrastructure such as irrigation, transportation, electricity, and so on. Consequently, only the farmers with sufficient capital can be successful.

The different farmer's reaction between the Northern and Southeastern part of PUA in dealing with poverty is also influenced by location factors. PUA in the North is located near the urban centers, thus increasing poverty will be easily followed by changing of their livelihood from agriculture to other jobs in the nearby cities, whereas PUA in the Southeast is located in more remote areas, thus there is a higher probability that poor people will stay on their cultivated land.

Regardless of the situation where PUA is closely related to small-middle scale economic activities, informality, and poverty, PUA in surrounding Jakarta, East and Northeast of JMA still has the capacity to support food security. Better accessibility and connectivity to markets and/or urban zone has made the PUA in this area market oriented and contribute to the food supply for the inhabitants. According to experience from the economic crisis in 1998 and 2007 the contribution of PUA to food supply in JMA is certainly required to overcome increasing food prices (Purnomohadi, 2001; Indraprahasta, 2013; Pribadi and Pauleit, 2015). PUA types in this area mainly consist of lowland and upland paddy and food crops, lowland horticulture, marine & coastal aquaculture, and livestock that produce staple food. Therefore, these five dominant PUA activities should become of a concern to strengthen food security in JMA especially at the time of crisis.

On the other hand, PUA in the Southwest of JMA do not have a capacity to support food security. Lack of accessibility and connectivity to markets and/or urban area has made this area become a retarded region compared to the other parts of JMA (Sunandar, 2006; Rachmawatie, 2010). As a result, PUA activities in this area tend to subsistence. It is different from PUA in the eastern part of JMA which is still able to support the market, although some of the farmlands are run by poor farmers. The findings indicate that the formation of subsistence agriculture is more influenced by limited access, infrastructure, and economic development instead of poverty.

The results of the study clarify the role of PUA which is important in the urban system regarding its relationship with small-middle size and informal urban economic activities, a poverty problem, and food security issue. Therefore, several recommendations to preserve and strengthen the socioeconomic function of the PUA in JMA can be given.

First, the connectivity between PUA and small-medium and informal urban economic activities is important because both activities mutually strengthen the livelihood of farmers and overall enhance peri-urban economy. Consequently, the preservation of PUA land will be supported. Although growing informal activities may indicate urban economic vulnerability and cause further exploitation of labor and the environment, their capability to support urban resilience in the time of crisis should not be neglected (Pelling and Mustafa, 2010). As urban development is increasingly threatened by the risks of global economic change and global environmental change (Moech and Gyawali, 2008; Douglass, 2013), the PUA and informal activities should be considered as urban components to support resilience, livability, and sustainability. Within this context, strengthening local livelihoods and improving the environmental situation in desakota regions should be addressed simultaneously as suggested by Moench and Gyawali (2008) and Douglass (2013). Our findings support the role of informal activities in cities in developing countries as a crucial issue for sustainable urban development (UN-Habitat, 2013).

Second, the varying relationship between PUA and urban poverty implies that specific policies are required in different areas of the PUA. Agricultural development programs in the global North should focus on increasing production and productivity as well as farmer's prosperity. Financial support should be given to the farmers, so that farmers' income as well as farming activities will increase on the good quality soil and where agricultural infrastructure is already developed. A similar policy cannot be applied to the PUA in the Southeast where agriculture is unreliable to become a sole livelihood. There, intensifying farming activities would threaten the forest land in the catchment area. Apparently, developing non agricultural jobs or small-middle scale industrial activities are important to reduce the number of farmers, increase farming efficiency, alleviate poverty, and release the forest from the PUA expansion. Complementary, designing payment for environmental services of PUA may be an effective means to generate more income and conserve the environment simultaneously (Smith and Sullivan, 2014).

Third, the results of the relationships between PUA and food security indicate that there are two different approaches that can be developed to maintain the PUA. The first one would be to conserve the existing PUA where it currently supports food security. It covers all agricultural land that produces staple food in surrounding Jakarta, East and Northeast of JMA as can be seen in Fig. 7(c). However, this is not an easy approach regarding the pressure of continuing urban expansion. Another approach would be to transform subsistence agriculture in the Southwest of JMA into commercial agriculture by developing technology, infrastructure, and connectivity with the market. The PUA in this area would then increase its capacity to support food security policy.

Applying a correspondence analysis coupled with a GWR model offers a useful method to define the socioeconomic role of PUA over the urban landscape of JMA. The results allow to identify indicators that can be used to measure the importance of PUA in dealing with the particular issues in a certain area. Besides, reliable statistical data and empirical analysis of PUA are required by urban planners to decide which area of PUA is worth enough to be supported by public policy that certainly need a spending from the government budget.

However, this method cannot be adopted when the statistical data are unavailable. Unfortunately, agriculture in most cities, especially in the developing countries, is regarded as a trivial activity, thus the data are difficult to be obtained (Douglass, 1998; Zezza and Tasciotti, 2010). We recommend to record agricultural activities in urban areas as a fundamental step to acknowledge the role of specific agricultural land in the urban system and integrate this into urban planning policy. This is particularly required for Asian megacities which are characterized by the existence of desakota region.

Some recommendations have been formulated to maintain the PUA as a part of the urban strategy to strengthen peri-urban economy, reduce poverty, manage informality, and increase food security. Still, another question remains related to the relationship between PUA and the environmental situation in JMA. Further analysis at a farm level is also required to formulate detailed policies of developing different functions of PUA in JMA.

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Paper III

Pribadi, D.O., Vollmer, D., Pauleit, S., in review. Understanding the impact of peri-urban agriculture in rapidly developing city regions on runoff and soil erosion. *Regional Environmental Change*.

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UNDERSTANDING THE IMPACT OF PERI-URBAN AGRICULTURE IN RAPIDLY DEVELOPING CITY REGIONS ON RUNOFF AND SOIL EROSION

Abstract

Negative effects of land use change on water resources are among the most important environmental problems widely found in rapidly developing urban areas. Preserving green open spaces, including peri-urban agriculture, has been emphasized in urban planning to maintain or enhance the water catchment capacity of a landscape. However, the effect of agriculture on water-related landscape functions varies depending on the type, distribution, and management of farmland. This paper analyzes the dynamics of agricultural land and its effect on runoff and soil erosion, in order to support agricultural land management in Jabodetabek Metropolitan Area (JMA) with Indonesia's capital Jakarta at its core. In 2012, agricultural land in JMA covered 53% of the total area, mostly located in the peri-urban zone. Peak Flow and Universal Soil Loss Equation (USLE) models allowed to quantify the increase of runoff and soil erosion in the three most important water catchment areas in JMA caused by an expansion of dryland agriculture and mixed gardens from 1983 to 2012. Critical zones which generate most of the runoff and soil erosion were identified in each of the catchment areas. While reforestation of farmland in these zones will be only an option on steep slopes given the great food demands and rural livelihood, adoption of a differentiated set of good agricultural management practices can make a substantial contribution to reduce flood risks and conserve the productivity of the land. A specific set of policy incentives should be designed to induce the application of these soil and water conservation practices.

Keywords : peri-urban agriculture, runoff, soil erosion, catchment areas, farmland management zone

1. Introduction

Rapid urban expansion has converted large tracts of agricultural and natural areas, and stimulated increasing local temperatures (urban heat island effect), pollution, fresh water scarcity, floods, and landslides, among other environmental problems (Dahiya, 2012; Singh, 2014). Environmental risks in urban regions escalate not only because of increasing frequency and intensity of natural hazards but mostly due to the increasing vulnerability of growing populations and socio-economic activities that are exposed to the hazard (e.g. Herslund et al. 2015).

One of the most important environmental issues which is widely found in urban areas is the effect of land use change on water resources. Impermeable surfaces and development of drainage systems that convey water runoff rapidly to the nearest stream increase the risks of fluvial floods, urban stormwater flooding, and decreasing water resources and quality (Wheater and Evans, 2009). Within the Asian context, the problem is particularly severe because strong population and economic growth are concentrated in a few megacities (Dahiya, 2012; Douglass, 2013), and most of these cities are located in deltas and coastal areas where upstream rainfall and marine tides surge amplify the flood risk (Chan et al. 2012).

Jakarta, the capital of Indonesia, has increasingly suffered from flooding. Widespread flooding occurred in 1996, 2002, and 2007, where flooding in 2007 had the worst impact for the population (Brinkman and Hartman, 2008; Douglass, 2013; Firman et al. 2011). In February 2007, 60% of the city region was flooded, 430,000 inhabitants were displaced from their homes, electricity and telecommunications were shut down in large parts of the city, and it caused an estimated total economic loss of more than US$ 453 million (Steinberg, 2007). Another big flood occurred in 2013 even though the amount of precipitation had been lower than in 2007 (Tempo, 2013a). Although the inundated area in 2013 was smaller than 2007, the total economic loss was higher, reaching US$ 3 billion as the flood hit the central business district and some affluent residential areas (Insurance Journal, 2013; Douglass, 2013).

Steinberg (2007) stated that the 2007 flood was caused by three factors: (1) lack of flood control infrastructure, (2) uncontrolled garbage dumping, and (3) increasing runoff due to urbanization and deforestation. Sea-level rise and land subsidence also contributed to the flood (Firman et al. 2011; Hanson et al. 2010). However, further hydrologic analysis of the flood in 2007 established that it had mainly been caused by successive rainstorms in the downstream and upstream areas of Jabodetabek Metropolitan Area (JMA) which encompasses Jakarta as an urban core and its peripheral areas namely Bogor, Depok, Tangerang, and Bekasi (Brinkman and Hartman, 2008). Interestingly, there was no evidence that the heavy rainfall was exacerbated by climate change, when viewed against a long set of monthly rainfall data since 1860 (see also Rustiadi et al. 2012, Firman et al. 2011).

In order to cope with the escalating flood risk, national and local governments of JMA have allocated US$ 4.3 billion to develop dams, canals, embankments, river normalization, etc. only for controlling water flow in the Ciliwung stream (Kompas, 2014), which is the largest river passing through Jakarta and the major source of fluvial flooding. However, the increasing magnitude and frequency of floods is generally outpacing governments' capacity to build costly flood prevention infrastructure (Kenyon et al. 2008). For instance, Jakarta’s flooding in 2013 broke the embankment of the west flood canal and increased the destructive power of the flood which then hit the central business district, some elite housing areas, and even the Presidential Palace (Tempo, 2013b). A new approach to sustainable flood management that emphasizes environmental management and socio-economic resilience has been suggested (Kenyon et al. 2008; Wheater and Evans, 2009; Plate, 2002). Within this context, land use planning coupled with engineering response are regarded as a more appropriate strategy to control future flood risks (Wheater and Evans, 2009; Tellman et al. 2015). Both aspects are important not only to protect society from flooding, but also increasing the resilience of people when their socio-economic activities are disturbed by flooding.

Recent studies and the trend of increasing flood damages in JMA emphasize the effect of land use change in both downstream and upstream areas on flooding. While it has been estimated that the drainage system, which is mostly located in the downstream urban areas, could have reduced 40% of people affected by

2007 flood if it was well maintained (Brinkman and Hartman, 2008), managing land use change in the upstream area is becoming more crucial. The Ciliwung watershed is particularly critical (Farid et al. 2010, Rustiadi et al. 2012). Therefore, the national and local government agreed to develop a joint program to minimize runoff and soil erosion in upstream areas that contribute to flooding and landslides in JMA (BPDAS Citarum-Ciliwung, 2011; BBWS Ciliwung-Cisadane, 2012).

As a consequence, the role of agricultural land in flood management has become important as it covered 53% of the total area of JMA in 2012 and mostly is located in the peri-urban region (Pribadi and Pauleit, 2015). Within the urban context, agriculture in the peri-urban is regarded to improve environmental quality as well as enhance resilience in socioeconomic crises including natural disasters. Peri-Urban Agriculture (PUA) can increase water retention, water infiltration, and groundwater recharge (Yokohari et al. 2000; Malaque III and Yokohari, 2007; Haase and Nuissl, 2007) as well as reduce flood risk (Kenyon et al. 2008; Wheather and Evans, 2009, Lee et al. 2015). Furthermore, PUA provides an open space which is able to reduce adverse impacts of flooding on buildings and settlements (Brody and Highfield, 2013). PUA also enhances regional food security, which is important to support the needs of underprivileged city dwellers in a socioeconomic crisis situation (Purnomohadi N., 2001; Indraprahasta, 2013; Pribadi and Pauleit, 2015). Therefore, Morris et al. (2010) stated that agricultural land in urbanizing areas has an important role in both flood mitigation and adaptation.

However, a view that supporting PUA will always improve the environment, especially in flood risk reduction, would be an oversimplification. Despite its ability to provide environmental benefits, it also can harm the environment when it is developed on unsuitable land or when farmers apply exploitative techniques. Excessive use of chemical compounds in agricultural activity pollutes the water (FAO, 1999; Vagneron, 2007; Hussain and Hanisch, 2014), soil compaction due to farming activities inhibits water infiltration and increases runoff (O'Conell et al. 2007), and open land for agriculture on steep slopes stimulates soil erosion (Adimihardja, 2006; Vis et al. 2012b). Unfortunately, rigorous analyses that examine the effect of agricultural land on flooding at a landscape level are relatively rare, as developing a model which is able to link small scale changes of farmland to larger catchment scales is complicated and/or the availability of spatio-temporal data is limited especially in developing countries (O'Conell et al. 2007; Wheater and Evans, 2009; Tellman et al. 2015).

This paper attempts to fill the gap by studying the dynamics of PUA and its effects on flood risk in JMA, in order to provide information in support of management of PUA. This study focuses on catchment areas of the three major watersheds in JMA as a part of the peri-urban region that significantly influences downstream flooding. Runoff and soil erosion are used as indicators of flood risk since increasing surface water and river sedimentation exacerbate flooding. The effect of PUA dynamics in each part of those catchments on runoff and soil erosion is explored, as a basis to suggest different zones for PUA land management. Therefore, the objectives of the paper are (1) to identify the changing type and distribution of PUA in the catchment area of the three watersheds, (2) to analyze the effect of PUA dynamics on runoff and soil erosion, and (3) to define PUA zoning that should be managed specifically to reduce runoff and soil erosion.

1. Materials and Methods

2.1. Research Area

Jabodetabek Metropolitan Area (JMA) is one of the biggest metropolitan areas in Asia (Douglass 2013). JMA covers a total area of 6,256 km^2 with a population of 28.0 million in 2010, distributed over 13 districts and municipalities. The research area focuses on the catchment area of three major watersheds - Cisadane, Ciliwung, and Kali Bekasi - as a part of the periurban zone of JMA, covering an area of 1,094 km^2 (Cisadane), 150.7 km^2 (Ciliwung), and 226 km^2 (Kali Bekasi). Cisadane has the largest catchment area with steep slopes in some parts of the area. The catchment area of Ciliwung is the smallest. It is dominated by steep slopes, and the main river goes through Jakarta and contributes most to economic damages from flooding. The catchment area of Kali Bekasi is larger than Ciliwung but it consists of more gentle slopes. All of the catchment areas are located in the south part of JMA as part of the Salak and Gede-Pangrango mountain ranges. Most of the rivers in JMA flows from the upstream area of those watersheds to the plain area in the north that covers

Tangerang district for Cisadane stream, Jakarta for Ciliwung stream, and Bekasi district for Kali Bekasi stream. A map of JMA and the research area is shown in Fig. 1.

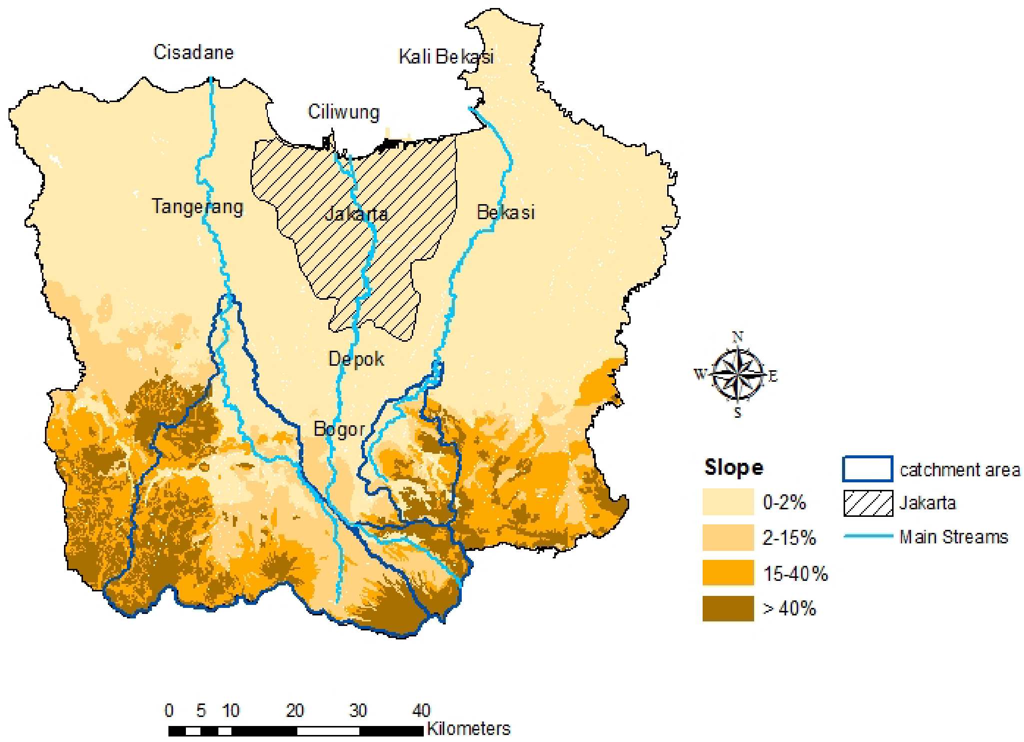

Fig. 1 Map of Jabodetabek Metropolitan Area and Its Three Catchment Areas

2.2. Analysis of PUA Dynamics

PUA dynamics within the study area were analyzed based on PUA land use change from 1983 to 2012. This period was chosen because urban expansion beyond Jakarta proper began in the early 1980s. Land use change was measured by overlaying JMA land use maps of 1983 and 2012 obtained from Pribadi and Pauleit (2015). Six types of PUA land use were distinguished: paddy field, inundated paddy field, dryland agriculture, mixed garden, plantation, and fishpond. The description of each PUA land use is shown in Table 1. Additionally, there were six other types of non-PUA land uses: water body, forest, bush, scrub, open space, and built up area. Gains and losses of each PUA category were identified, and its relation with gains and losses of non-PUA land were also assessed. The analysis was done by using Spatial Analyst tools of ArcGis 9.3 software package.

Table 1. PUA Land Use Features

PUA Land Use	Description
Paddy field	Rainfed paddy field only cultivated in the rainy season
Inundated paddy field	Irrigated paddy field cultivated throughout the year
Dryland agriculture	Non-irrigated farmland cultivated with annual plants in horticulture or other food crops such as corn, sweet potato, etc.
Mixed garden	Non-irrigated farmland cultivated with a mix of annual and perennial plants
Plantation	Non-irrigated farmland cultivated with perennial plants
Fishpond	Covered by water

2.3. Measuring the effect of PUA Dynamics on runoff and soil erosion.

Gains and losses of PUA land affect the quantity of runoff and soil erosion. In order to measure their effect on runoff, we used a Peak Flow Model developed by Vis et al. (2012a) that has been applied for Cisadane and Ciliwung watershed in 2010 and was validated for the Ciliwung watershed. Principally, the model is intended to define the influence of land use change in each part of the catchment area (micro scale) on runoff (catchment scale). The model considers runoff as a complex function of rainfall, slope, soil, form of the catchment area, and land use change, which are specific for each watershed. It was developed based on the technique of a spatially distributed hydrograph (SDUH) to delineate areas in the catchment according to their influence on the peak flow at the outlet of the catchment. A raster GIS function of ArcGIS Spatial Analyst was used to establish the excess rainfall in each raster cell, and calculate the quantity and travel time of surface water flow from each raster cell to the outlet. The calculation was done by determining the flow path, then the excess rainfall and its travel time through each individual cell along the flow path. Cell values were summed up to estimate a cumulative discharge and travel time at the outlet, as well as compose a runoff hydrograph. As noted, a hydrograph is a graph showing the relationship between water flow and time at a specific point in a river.

The contribution from raster cells to the hydrograph at various stages was then mapped for the catchment to provide information about the sensitivity of peak discharges to land use changes in the catchment. This map consists of lines connecting points at which runoff arrives at the same time at the outlet called isochrones. Since the model aims to establish the impact of land use change on runoff, it was developed based on an assumption of a one hour rainfall in the catchment derived from the annual rainfall isohyets map.

The model used maps of annual rainfall isohyets, topography, stream network, delineation of the catchment area of watersheds, and land use as input data. All maps were obtained from Vis et al. (2012a), except the land use data. Land use maps for 1983 and 2012 were used to analyze the effect of PUA land use change on runoff. All of the data are in a raster form with a cell size of 30 m^2. Every type of land use has a curve number and Manning coefficient which were used to determine the proportion of rainfall that becomes direct runoff, and both parameters were derived from US Soil Conservation Services (SCS) and adjusted to the prevailing land use types in Indonesia (Vis et al. 2012a). Particularly for PUA, inundated and non-inudated paddy fields have the highest capacity to retain runoff which is even higher than under forest cover; fishponds have no capacity as they are covered by water, while other PUA land have a moderate retention capacity between built up areas and forests.

There are two outputs of the model comprising (1) comparison of the runoff hydrograph in 1983 and 2012, and (2) an isochrones map 2012 showing zones that contribute most to the formation of peak discharge at the outlet. The comparison indicated the impact of land use change, including PUA, from 1983 to 2012 on runoff, while the isochrones map was used to define the PUA proportion in a zone that determines peak discharge at the outlet in 2012. The diagram of the model can be seen in Fig. 2.

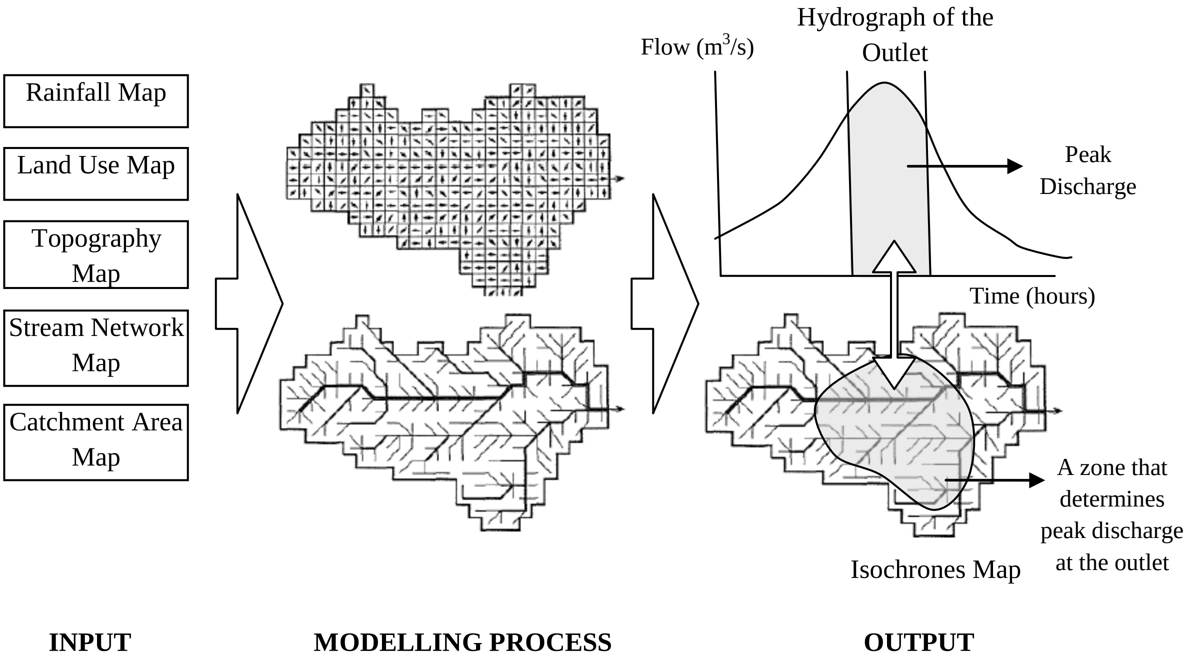

Fig. 2 Diagram of The Peak Flow Model

A Java Erosion Model developed by Vis et al. (2012b) was used to analyze the effect of PUA dynamics on soil erosion. This model was developed based on USLE (Universal Soil Loss Equation Model) where the equation is

$$A = R \times K \times L \times S \times C \times P$$

Note:
A : annual soil loss per unit area.
R : rainfall erosivity factor
K : soil erodibility factor
L : the slope length factor
S : the slope gradient factor
C : cropping/management factor
P : the erosion-control practice factor

The model uses the 1:250,000 soil map of Java of Lembaga Penelitian Tanah (1966) consisting of 55 soil types; the 1:1,000,000 of rainfall erosivity map of Java of Bols (1978); and DEM /Slope from SRTM 2000 (30 m^2 of resolution) to obtain the R, K, L, and S factors as physical parameters which cannot be influenced by management. It also includes a combined CP factor matrix as a function of land use, management level, and slope class (Appendix 1). The land uses were adjusted to the classification of the land use map available for our study areas. The slope class was divided into 4 classes comprising 0-2% (low), 2-15% (moderate), 15-40% (high), >40% (very high). The management level of each land use type was derived from Hammer (1981) consisting 3 options as follows:

- Bad management: where cultural management practices are limited and mechanical management practices are restricted to very simple measures like strip cropping.
- Actual management: represents the actual situation in 1980 where mulching and fertilizer were used in some agricultural lands and mechanical management practices were applied in low or moderate ways (traditional terraces).
- Good management: where surface mulching, fertilizer application, intercropping, and crop diversification are applied, and mechanical management practices concentrate on terracing, either outward sloping terraces or bench terraces.

This study used all of the input data which were provided by Vis et al. (2012b) except the land use map. As with the Peak Flow Model, the Java Erosion Model used raster data input with a resolution of 30 m^2. It was assumed that the situation in 1983 would follow actual management levels since that category was parameterized based on the actual situation in the 1980's. The management level in 2012 was analyzed based on bad and good management scenarios, since the information about the actual management was unavailable. As noted, since the soil is sealed off by water surfaces and built-up area, this model mainly evaluates soil erosion on management of cultivated land.

2.4. Zoning analysis of PUA land management to reduce runoff and soil erosion

Mapping zones that influence runoff and soil erosion is important to define specific approaches for PUA land management in different areas of the catchment. Based on the isochrones map for 2012 generated by the Peak Flow Model, a critical zone to manage runoff was defined as a zone that determines peak discharge at the outlet.

On the other hand, a critical zone to mitigate soil erosion was defined by omitting the management factor (*C* and *P*) variables of the USLE equation, resulting in a so-called the Bare-Soil Model. This model reflects soil losses that would occur on fallow land during the whole year. It can be used to define the area at risk of erosion (soil erosion reached > 500 tons/ha/year). Thus together with the area that should be reforested (>30% of slope), both criteria were set to avoid serious soil degradation upstream and sedimentation problems downstream (Vis et al. 2012b).

The isochrones map for 2012 and the map from the Bare-Soil Model were overlaid to define zones that influence runoff and soil erosion. As a result, there are 5 zones in every catchment area: (1) a non-critical zone to runoff and soil erosion, (2) a critical zone to runoff, (3) a critical zone to soil erosion, (4) a critical zone to runoff and soil erosion, and (5) a reforestation zone. Then, the type and distribution of PUA land in each zone were identified, so that strategies to manage PUA in every zone can be explored. The diagram of PUA zoning analysis is shown in Fig. 3.

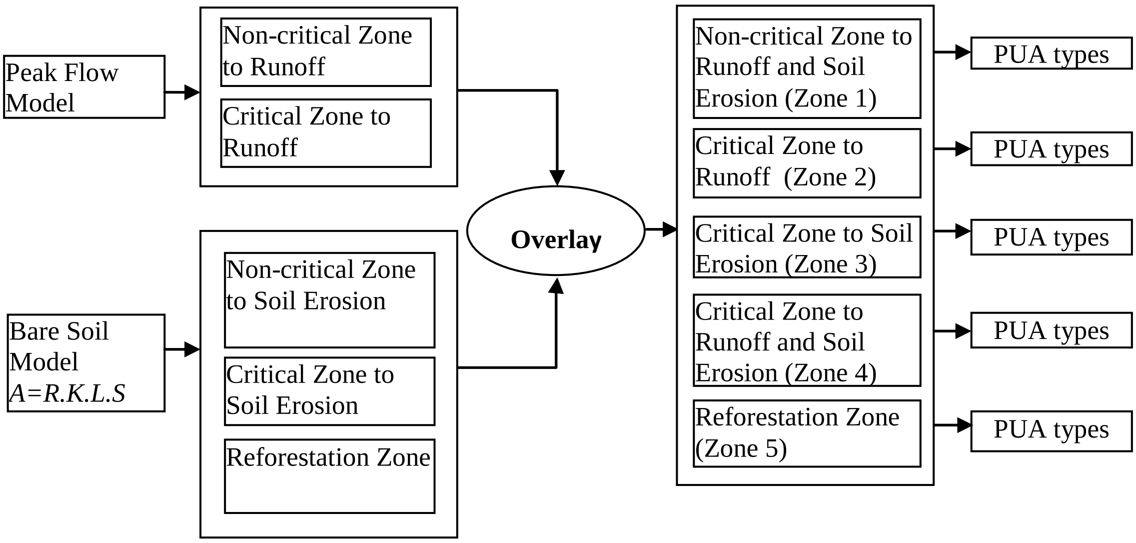

Fig. 3 Diagram of PUA Zoning Analysis

2. Results

3.1. PUA land dynamics in each catchment

Agricultural land in all three catchments has expanded and covers a large proportion of land use. From 1983 to 2012, agricultural land in Kali Bekasi, Ciliwung, and Cisadane catchment increased from 50% to 56%, 14% to 35%, and 30% to 55% of the total area respectively. Dryland agriculture and mixed gardens have become dominant agricultural land use types in all catchments, while inundated paddy fields in sizeable proportion was only found in Kali Bekasi and Cisadane.

Land use changes in these areas were dominated by losses and gains of farmland. Due to urbanization pressure, agricultural land experienced loss, but it shifted and largerly expanded to forest area. Farmland expansion has contributed to 78%, 74%, and 82% of total forest loss in Kali Bekasi, Ciliwung, and Cisadane respectively. Again, dryland agriculture and mixed gardens experienced the greatest losses and gains in all catchments. Only in Kali Bekasi and Cisadane, the dynamics of agricultural land were also characterized by the loss of paddy fields and gains of inundated paddy fields.

The overall and simultaneous increase of agricultural land and built-up areas in all catchments has pressured the forests that also play an important role in the upstream areas' hydrological system. A detailed overview of the losses and gains of land use in the three catchment areas from 1983 to 2012 is shown in Fig. 4.

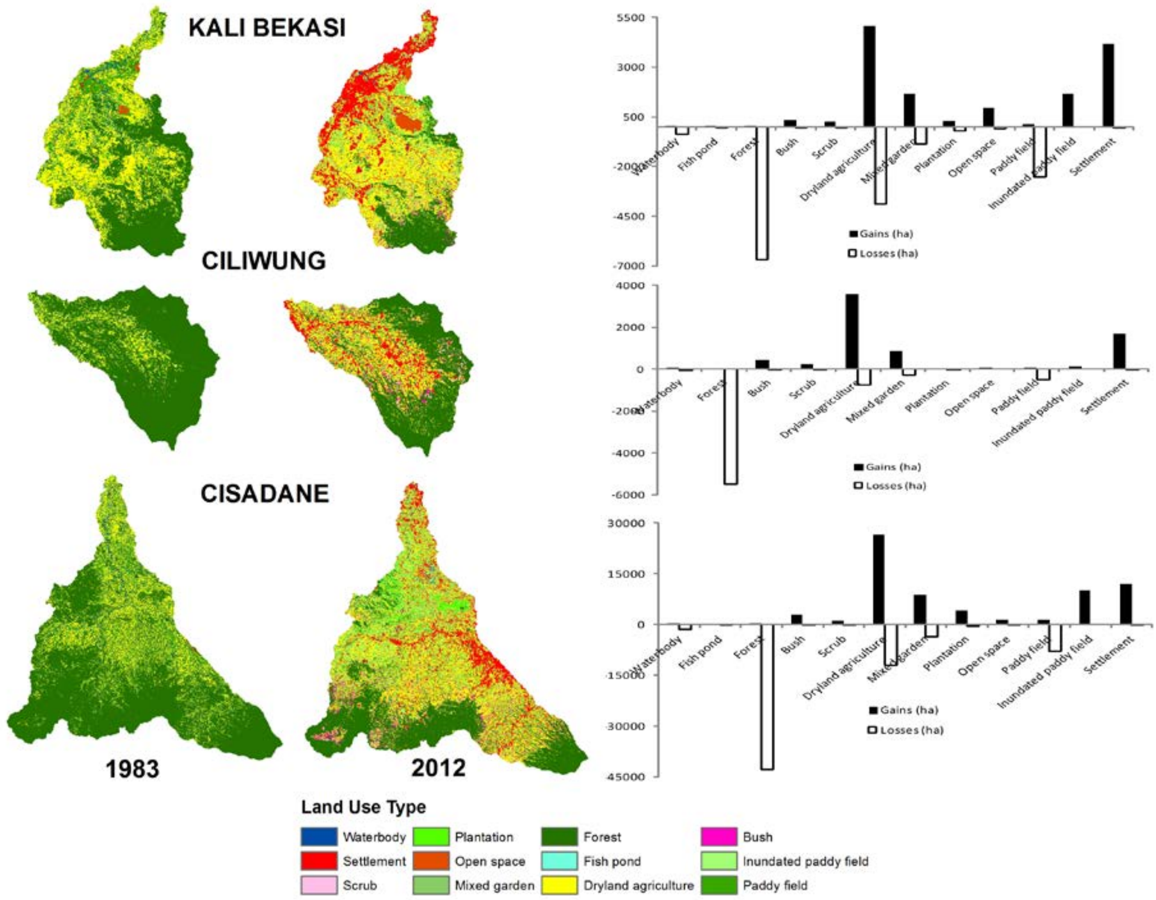

Fig. 4 Land Use Change in Three Catchment Areas from 1983 to 2012

2.2. The effect of PUA dynamics on runoff

The impact of PUA dynamics on runoff is different for each catchment area as can be seen in Fig. 5. For Kali Bekasi, the difference in hydrographs at the outlet for 1983 and 2012 was characterized by an increase of the maximum peak flow by 18.5 %, and an increase of the total runoff by 11.8 %. The time to reach the maximum peak flow at the outlet was one hour less, declining from 11 to 10 hours. It occurred because the zone which determines peak discharge experienced a loss of PUA due to urbanization but it largerly expanded on forest land. As a result, the zone was dominated by agricultural land (70%), mainly were dryland agriculture (48 %), mixed gardens (11 %), and inundated paddy fields (9 %).

For Ciliwung, comparison between hydrographs of 1983 and 2012 showed an increase of the maximum peak flow by 15.2% and an increase of the total runoff by 12.2%. The maximum peak flow at the outlet was reached after 5 hours in 2012 instead of 6 hours in 1983. It was mainly caused by land use change in the zone that determines peak discharge which was dominated by conversion of PUA to built up areas followed by larger farmland expansion on forest area. Accordingly, this zone was dominantly covered by agricultural land (40 %) and forest (40 %) in 2012. This agricultural land mainly consisted of dryland agriculture (32 %), mixed gardens (7 %), and inundated paddy fields (1 %).

For Cisadane, the change of agricultural land in the catchment area had also an impact on the hydrographs of 1983 and 2012. The maximum peak flow increased by 27.7%, while the total runoff increased by 10.5%, and the maximum peak flow at the outlet was reached after 11 instead of 12 hours. As in the other catchments, the zone that determines peak discharge experienced loss of PUA land due to urbanization, whereas PUA overall expanded and converted most of the forest area. Consequently, this zone was dominated by 71% of agricultural land in 2012, mainly of dryland agriculture (42 %), inundated paddy fields (12 %), mixed gardens (10 %), and other farming activities.

These results showed that agricultural land in the three catchment areas has become a dominant land use in the zone that determines peak discharge at the outlet. Maximum peak flows and total runoff in all watersheds have increased and the peak discharge are reached one hour earlier due to land use change.

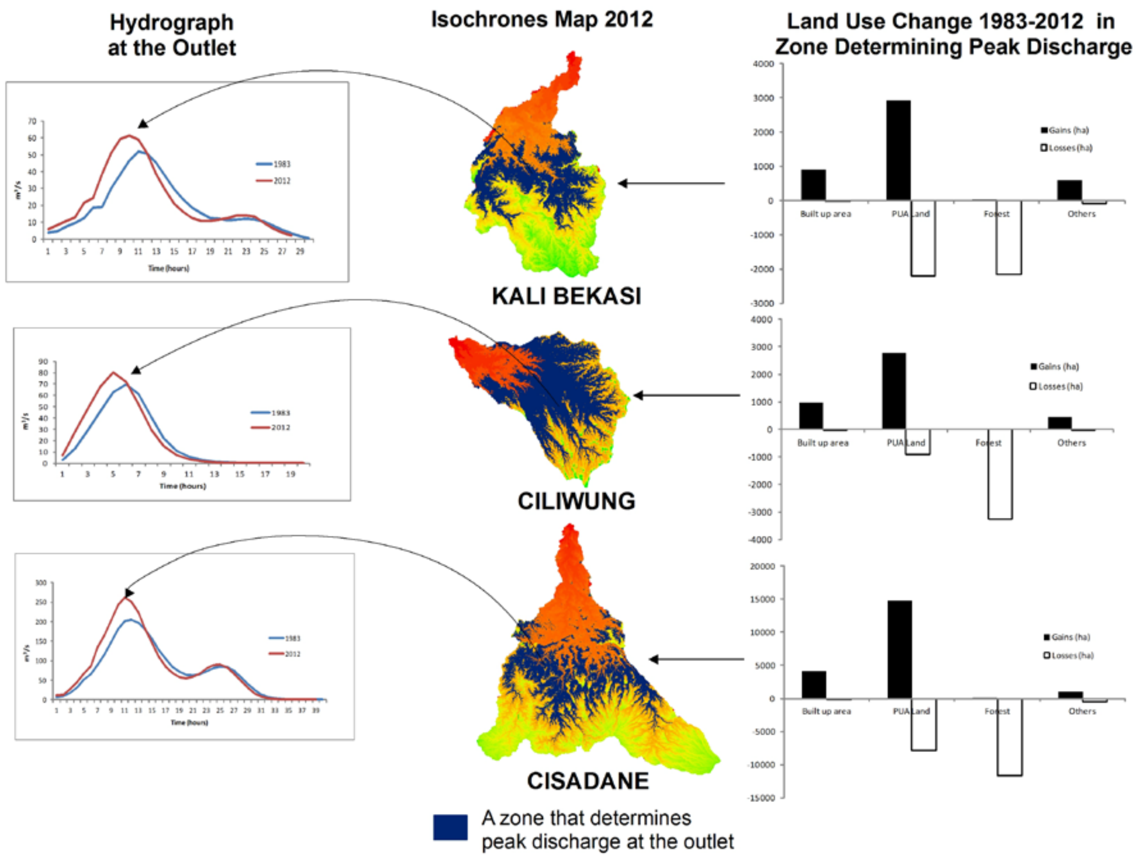

Fig. 5 The Results of A Peak Flow Model (Hydrograph 1983-2012 and Isochrones Map 2012) and Land Use Change 1983-2012 in Zone that Determines Peak Discharge 2012

2.3. The effect of PUA dynamics on soil erosion

PUA dynamics in the three catchment areas have different impacts on soil erosion as can be seen in Fig. 6. In Kali Bekasi, soil erosion under actual management of agricultural land in 1983 reached 1.8 million tons/year. Adopting good management practices would lead to a decrease of the amount of soil erosion by 30 % despite the expansion of agricultural land in 2012. However, soil erosion would increase by 161 % compared to actual management of land if bad management practices were applied to all farmland. Obviously, applying good management practices would even reduce soil erosion in this catchment area in 2012 relative to the situation in 1983.

Soil erosion under actual management in the Ciliwung in 1983 reached 0.4 million tons/year. Along with the shifting and increasing PUA land until 2012, soil erosion would increase approximately by 120 % even under good management when compared to the situation in 1983 and by 674 % under bad management.

The situation in Cisadane showed that soil erosion in 1983 reached 3 million tons/year under actual management. Expansion of the PUA land in 2012 would lead to an increase of soil erosion by 43 % under good management when compared to the situation in 1983 and by 450 % under bad management. In this area, good management of land is therefore able to lower soil erosion considerably.

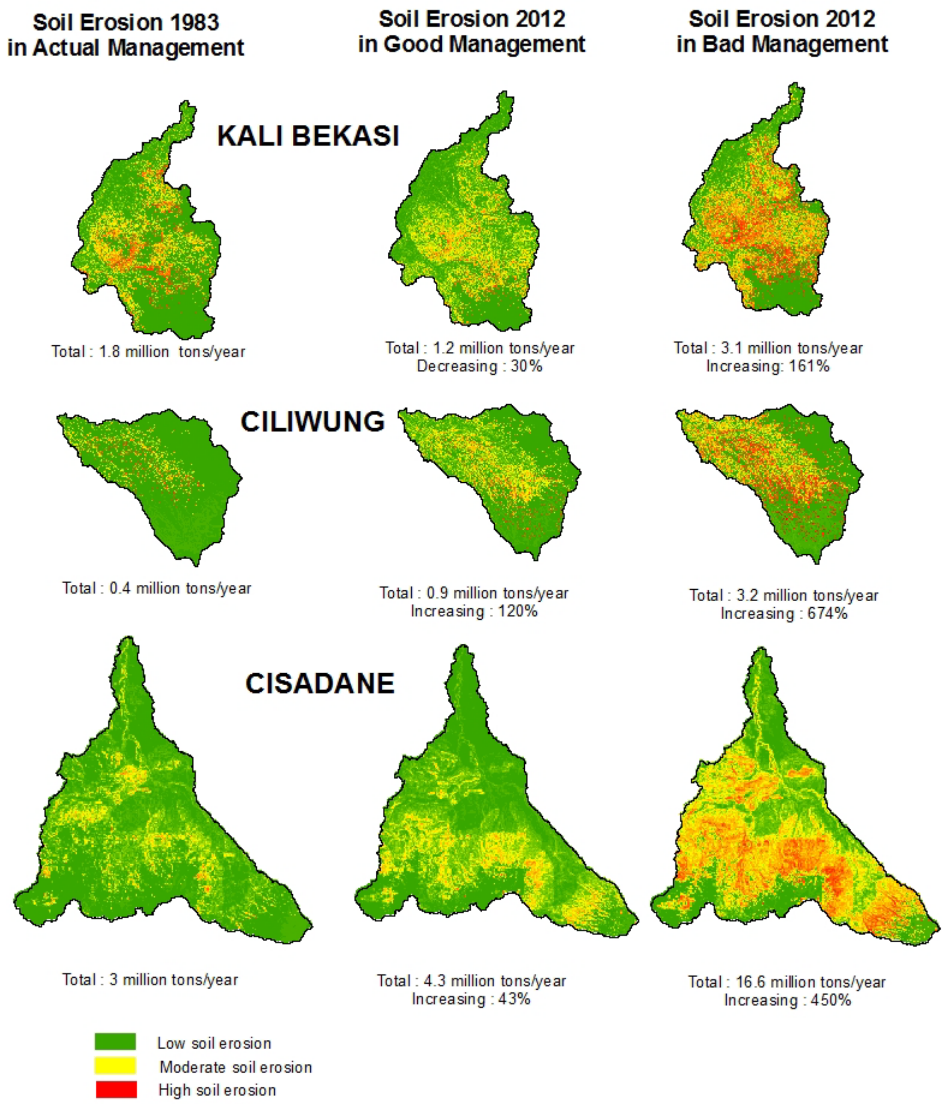

Fig. 6 The Result of USLE Model in 1983 and 2012

3.4. Zoning of PUA land management to reduce runoff and soil erosion

The distribution of agricultural land within the different critical zones defined for each catchment area is shown in Fig. 7. In Kali Bekasi, 74 % of agricultural land was predominantly developed in the critical zones (zone 2, 3, and 4). In these zones, agricultural land was dominated by dryland agriculture, mixed gardens, and inundated paddy fields, respectively. Similar to Kali Bekasi, 81 % of agricultural land in Ciliwung was also located in the critical zones (zone 2, 3, and 4). There were two major agricultural types in the zone consisting dryland agriculture and mixed gardens. Fifty eight percent of agricultural land in Cisadane was located in the critical zones (zone 2, 3, and 4), but 33 % was sited in the non-critical zone to runoff and soil erosion (zone 1). Compared to the other catchments, Cisadane had a bigger proportion of agricultural land in the non critical zone, thus the effect of agriculture on runoff and soil erosion was lower. Agricultural land in these zones were dominated by dryland agriculture, mixed gardens, and inundated paddy fields, respectively.

Overall, it can be seen that most of the agricultural land was located in the critical zones. Furthermore, a small proportion of agricultural land was located in areas we would suggest designating for reforestation due to their slope (9 % in Kali Bekasi, 10 % in Ciliwung, and 9 % in Cisadane).

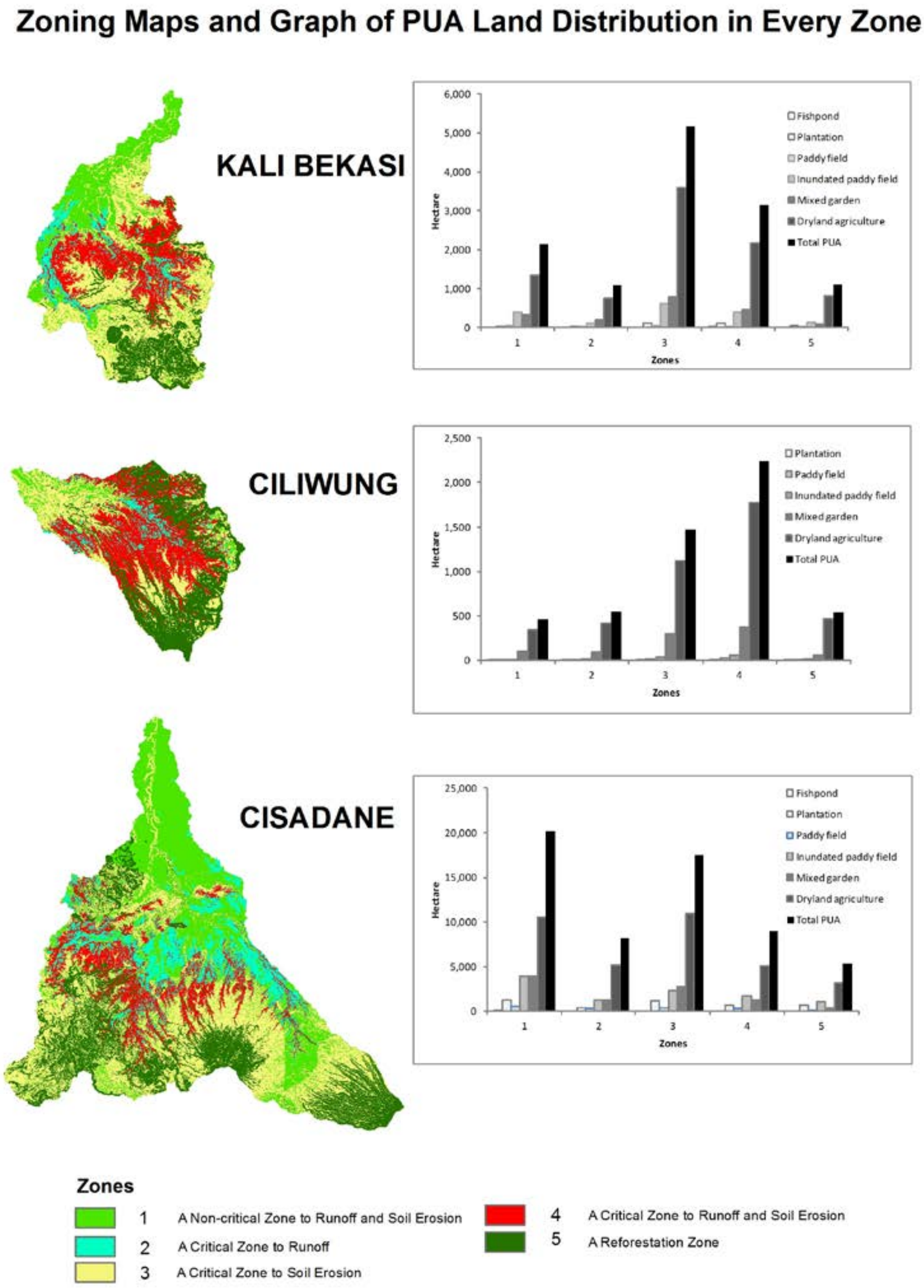

Fig. 7 The Results of Agricultural Zoning Analysis

Discussion and Conclusions

Results showed that PUA land in the three catchment areas (Kali Bekasi, Ciliwung, and Cisadane) has expanded from 1983 to 2012 and has become the dominant land use. Despite an overall decline in agricultural land use in JMA due to urban growth (Pribadi and Pauleit, 2015), agricultural land use in the study area increased simultaneously with urban expansion. Apparently, the development of settlements and the road network in this area has connected farmland to the urban market, thus enhancing the development of agricultural land. Certainly, this situation will not continue if the urban zone keeps growing and displaces PUA, but now the local and national governments are seriously trying to restrict urban expansion for maintaining the quality of the catchment areas. However, it should be recognized that expansion of PUA in the catchment areas may be harmful, for instance for biodiversity (Wang et al. 1997; Foley, et al. 2005), and preservation of soils and groundwater quality (O'Connell et al. 2007; Dale and Polasky, 2007; Kenyon et al. 2007; Wheater and Evans, 2009; Balali et al. 2011). Therefore, the effect of PUA land needs to be assessed to support decision-making with information on where, how, and for what reasons PUA has to be preserved or should be replaced by forest (Aubry et al. 2012).

The results of the Peak Flow Model show that the critical zone to runoff is dominated by agricultural activities in all three catchments. Expansion of agricultural land, and in particular that of dryland agriculture and mixed gardens within this zone, increases the water discharge, shortens the time of peak flow at the outlet, and potentially increases flood risk downstream. Between the three catchment areas, Ciliwung has the biggest impact on flooding because this area is relatively narrow and steep. Therefore, it is difficult to retain the surface water and peak flow at the outlet are more quickly reached than in the other catchments. Furthermore, the Ciliwung river flows directly through Jakarta's highest density of population and social-economic activities. Although the percentage of agricultural land within the critical zone to runoff is only 40%, its impact on flooding should be seriously considered in future land use policies.

The capability of the other two catchment areas to retain and infiltrate water also decreased, although their impact on flooding is not as serious as Ciliwung. Both have a larger area with gentler slopes, and their streams do not lead to Jakarta proper. Agricultural land occupied 71 % (Cisadane) and 70 % (Kali Bekasi) of the critical zone to runoff, meaning farmland can considerably influence the volume and timing of peak flow at the outlet. Despite their overall lower impact on runoff regimes, a plan to channel excess water from the Ciliwung to Cisadane therefore appears to be problematic since this could even exacerbate flooding in urban Tangerang downstream of the Cisadane. This situation, coupled with the high cost of land for building dams, canals, artificial lakes, and other engineered structures, has led the government to consider plans such as building a deep tunnel for channeling the excess surface water as quickly as possible to the sea (Kompas, 2013). This measure is widely criticized due to its costs and the threats to a potential source of freshwater. Instead, options for reducing runoff as well as raising water infiltration in the upstream areas should be considered (BPDAS Citarum-Ciliwung, 2011; BBWS Ciliwung-Cisadane, 2012).

The result of USLE model shows that PUA expansion from 1983 to 2012 generated different quantities of soil erosion depending on the physical characteristic of the catchment areas and the management level of agricultural activities. Implementing good management of farmland in Kali Bekasi even would reduce soil erosion when compared with actual management in 1983. Results indicate that the management factor is more important than physical factors as the catchment area is relatively large and consists of gentle slopes. On the other hand, a different situation was found within the Ciliwung catchment area where the expansion of agricultural land intensified soil erosion both under good and bad management. Here, physical factors are more important than the management factor to determine soil erosion, because of the narrowness and steepness of this area. Therefore, further development of agricultural land in this area needs to be strictly controlled.

Increasing soil erosion both under good or bad management was also found in Cisadane due to PUA expansion, even though the increase was less strong than in the Ciliwung catchment. Under good management, soil erosion would increase less than one and a half times of soil erosion 1983, but under bad management, it would sharply increase four times. Therefore, adoption of good practice of management of farmland such as mulching, intercropping, crop rotation, and teraccing would effectively contribute to reduce soil erosion but increase of PUA land also needs to be controlled.

Based on the above results, it can be shown that the expansion of PUA on the three catchment areas strongly increased runoff and soil erosion. Dryland agriculture has become the predominant farming type, mostly in the form of horticulture (Pribadi and Pauleit, 2015). As it involves labor and is capital intensive, most of the farmers exploit their land to secure their harvest and their capital return. Farming continuously without a break, coupled with open land without cover crops, intensifies runoff and soil erosion (Agus and Husen, 2006).

Influencing agricultural land management is critical to retain water and allow it to infiltrate into the soil, as well as reduce soil erosion. In emerging anthropogenic catchments (i.e. catchment areas that are affected by human activities) solutions cannot only rely on preservation of natural areas to maintain hydrological process (O'Conell et al. 2007). Moreover, reforestation of agricultural land to reduce runoff and soil erosion is hardly to be considered as an alternative due to the important role of agriculture in supporting life of the poor, enhancing the livelihood of peri-urban dwellers, and strengthening food security in JMA (Pribadi and Pauleit, 2015; Pribadi and Pauleit, 2016). Only on the steep slopes (9-10% of farmland in all three cachtments) reforestation is to be considered absolutely necessary while soil and water conservation principles should be applied to the remaining farmland in the critical zones.

Therefore, specific practices should be adopted to maintain agricultural land in the critical zones that generate runoff and soil erosion. Preventing soil compaction, minimizing soil erosion, nutrient management, soil organic matter management, controlling runoff, increasing water infiltration, and efficient irrigation systems are some of the important principles to be adopted. For developing and implementing a set of tailored policies, more attention to the social-economic system needs to be given to motivate the farmers applying soil and water conservation practices. Kenyon et al. (2008) argued that agricultural areas can play a bigger role in flood management, but a collaborative and participatory approach that involves the farmers and other related stakeholders needs to be adopted for this purpose. Farmer involvement in environmental management is not only effective to improve environmental quality, but it can also help urban dwellers understand the multi-functionality of agricultural land and appreciate why agricultural land needs to be preserved in peri-urban areas. As Gutman (2007) stated, provisioning ecosystem services will become a way to preserve agricultural land in the urban system.

The involvement of farmers in environmental management needs to be encouraged by different approaches depending on their farmland location in the critical and non-critical zones. Farmers in the critical zones should be supported by incentives and technical assistance in implementing water and soil conservation principles. Farmers in the non-critical zones can be supported by incentives and management assistance to maintain land productivity. Farmers in the reforestation zone should be moved to other areas or trained for getting another job. Furthermore, this PUA zoning can help the government develop programmes to enhance farmers providing ecosystem services from their farmland. A compensation formula that can stimulate the farmers to get involved in environmental management which accounts for the position of agricultural land and its effect on the environment should be considered as a promising approach (Broch et al. 2013).

Unfortunately, government agencies still prefer to use an engineered structural approach rather than a social-economic approach. They tend to focus on building infiltration wells as well as replanting and reforestation programs that fail due to lack of maintenance and monitoring, promoting agro-forestry which is not compatible with the existing agricultural system, and even now, planning to build several dams in the catchment areas to retain runoff (BPDAS, 2011; BBWS, 2012). All these programs rarely involve farmers who are the daily managers of most of the land in the catchment areas. Therefore, the programs cannot be sustained when the governments' projects come to an end (Konsorsium Penyelamatan Puncak, 2014).

Obviously, the role of PUA in environmental management in JMA is important. Rapid urban expansion has pushed farming activities from the downstream to upstream areas (see also Martellozzo et al. 2015). Currently, agriculture has become an important source of income and food supply that simultaneously determines the capacity of the catchment to retain and infiltrate water. Production and conservation functions of the PUA need to be developed simultaneously to address this situation. However, collaboration and coordination between stakeholders at a landscape level (upstream' inhabitants as producers and downstream' inhabitants as beneficiaries) is required to reconcile agriculture and environmental interests and support the continued provision of ecosystem services (Pinto-Correia and Breman, 2009; Prager et al. 2012).

This study contributes to PUA planning issues in Asian cities where there is a need to define the relationship between specific agro-ecosystem services with its landscape composition and configuration under the influence of rapid peri-urban land use change (Lee et al, 2015). It was based on the spatial analysis of the PUA land use change, and spatial modeling of its impact on runoff and soil erosion. The approach for evaluating the effect of PUA activities on the environment over the landscape and developing zoning analysis for PUA land management used already existing methods, however, their combination was novel in particular in the context of a strongly developing city region of Asia. Since this study only focussed on management of water quantity, a complementary approach is also needed to assess water quality issues which also closely related to PUA management.

Further calibration of the Peak Flow model is needed to increase its accuracy, although some observations have shown that the outputs from the runoff model do match quite well data from runoff of extreme events (Vis et al. 2012a). Furthermore, data of current agricultural land management need to be collected to measure recent soil erosion. Higher accuracy and updated data are required to assess the effect of soil and water conservation practices in agriculture, thus some scenarios can be built to define the best alternative of PUA land management. As a complement, in-depth study at the farming level will support a collaborative and coordinated action to strengthen the multi-functionality of PUA especially in provisioning ecosystem services. While this research was restricted to a particular case study area, the topic of peri-urban agriculture is of large relevance to all growing city regions in the world, in particular in the context of Asian cities in deltas and river basins such as JMA. It is suggested that the approach developed in this study offers potential for wider application to assess the hydrological impacts of land use changes in rapidly developing urban regions and develop strategic options for sustainable land use management, with a particular emphasis on peri-urban agriculture.

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Appendix 1. Table of CP Factors

Land Use	Slope (%)	CP Factors		
		Good	Bad	Actual
Built-up Area	0 - 2	0.05000	0.05000	0.05000
Built-up Area	2 - 15	0.05000	0.05000	0.05000
Built-up Area	15 - 40	0.05000	0.05000	0.05000
Built-up Area	> 40	0.05000	0.05000	0.05000
Paddy field & Inundated Paddy Field	0 - 2	0.01000	0.01000	0.01000
Paddy field & Inundated Paddy Field	2 - 15	0.01000	0.01000	0.01000
Paddy field & Inundated Paddy Field	15 - 40	0.01000	0.01000	0.01000
Paddy field & Inundated Paddy Field	> 40	0.01000	0.01000	0.01000
Dryland Agriculture	0 - 2	0.04450	0.31000	0.11000
Dryland Agriculture	2 - 15	0.06250	0.33000	0.14500
Dryland Agriculture	15 - 40	0.09550	0.36000	0.23000
Dryland Agriculture	> 40	0.13650	0.44000	0.32000
Plantations	0 - 2	0.00450	0.22500	0.04680
Plantations	2 - 15	0.01040	0.25400	0.06570
Plantations	15 - 40	0.01990	0.28600	0.08640
Plantations	> 40	0.03380	0.32000	0.11700
Mixed garden	0 - 2	0.02230	0.15500	0.05500
Mixed garden	2 - 15	0.03130	0.16500	0.07550
Mixed garden	15 - 40	0.04780	0.19800	0.11500
Mixed garden	> 40	0.06830	0.22000	0.15500
Forest	0 - 2	0.00020	0.00050	0.00035
Forest	2 - 15	0.00050	0.00100	0.00075
Forest	15 - 40	0.00100	0.00150	0.00125
Forest	> 40	0.00100	0.00150	0.00125
Bush and Scrub	0 - 2	0.00100	0.00100	0.00100
Bush and Scrub	2 - 15	0.00150	0.00150	0.00150
Bush and Scrub	15 - 40	0.00200	0.00200	0.00200
Bush and Scrub	> 40	0.00200	0.00200	0.00200
Open Space	0 - 2	0.00500	0.02000	0.02000
Open Space	2 - 15	0.01000	0.05000	0.05000
Open Space	15 - 40	0.02000	0.07000	0.07000
Open Space	> 40	0.02000	0.07000	0.07000
Water Body and Fishpond	0 - 2	0.00000	0.00000	0.00000
Water Body and Fishpond	2 - 15	0.00000	0.00000	0.00000
Water Body and Fishpond	15 - 40	0.00000	0.00000	0.00000
Water Body and Fishpond	> 40	0.00000	0.00000	0.00000

Paper IV

Pribadi, D.O., Zasada, I., Müller, K., Pauleit, S., in review. Multifunctional adaptation of farmers as response to urban growth in the Jabodetabek Metropolitan Area, Indonesia. *Journal of Rural Studies*.

MULTIFUNCTIONAL ADAPTION OF FARMERS AS RESPONSE TO URBAN GROWTH IN THE JABODETABEK METROPOLITAN AREA, INDONESIA

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Abstract

Urban growth in Asian megacities has led to large peri-urban areas, which are characterized by a typically complex and fragmented pattern of urban-rural land use called desakota. In order to support urban resilience and sustainability, conservation of farmland and multifunctionality of agriculture in the peri-urban have been proposed to simultaneously provide livelihood for farmers, commodity production, and public benefits from ecosystem services. Nevertheless, how rural-traditional farming can be sustained during urbanization and develop multifunctional practices still remains a critical issue. This research aims to investigate farmers' adaptation behaviour in response to urbanization pressure and analyze their capability to develop multifunctional agriculture. The empirical study is based on farmer interviews (N=101) in the Ciliwung upstream area, which is the most important watershed in the Jabodetabek Metropolitan Area (JMA), Indonesia. Two main agricultural types can be distinguished: paddy rice and horticultural farming. Due to urbanization pressure, paddy rice survived as subsistence farming on the fragmented land between settlements, whereas horticulture appeared as economically motivated farming in the distant area near the forest. These types feature differences in the provision of and trade-off between multifunctional farming benefits, such as income generation, employment, commodity distribution, and environmental services. Farmers' decision making for multifunctional farming activities to unlock full potential of urban demand for food, recreation, and environmental health mainly depend on (i) their individual capacity, (ii) intrinsic motives, and (iii) land tenure situation. Some strategies have been suggested to support farming transition to strong multifunctionality as a key to preserve farmland within peri-urban planning.

Keywords: Peri-urban agriculture, farmer adaptation, farm-level transition, multifunctional agriculture.

1 Introduction

Urbanization in Asia is characterized by the rapid agglomeration of people and economic activities in megacities (Douglass, 2013; Swerts and Denis, 2015). The built-up areas often expand into the already densely populated peri-urban agricultural land, and create a specific feature called "desakota", where urban and rural systems are intermingled to form a seemingly chaotic urban-rural land use pattern (McGee, 1991; Yokohari et al., 2000). Recently, more than 10 km^2 farmland in urbanized regions in Asia has been converted daily due to the growth of the urban population by over 45 million a year (Dahiya, 2012).

Jabodetabek Metropolitan Area (JMA), which encompasses Jakarta as the core city surrounded by municipalities and districts of Bogor, Depok, Tangerang, and Bekasi, represents a typical example of this phenomenon. Therefore, JMA has become one of the fastest growing megacities in the world (Cox, 2011; World Bank, 2015). The increase of population is followed by issues of poverty and food insecurity (Rustiadi et al., 2015). Furthermore, due to uncontrolled urban encroachment, the region is increasingly prone to flood and landslide incidences (Rustiadi et al., 2015; Remondi et al., 2016), rising air temperatures (Effendy, 2009; Tokairin et al., 2010), and a diminishing capability to provide ecosystem services such as fresh water, biodiversity conservation, and recreational areas (Vollmer et al., 2016).

To address these issues, the preservation of green open space in the peri-urban has become increasingly important, and particularly that of agricultural land which covered 52% of JMA's area in 2012 (Pribadi and Pauleit, 2015). Peri-urban agriculture (henceforth called PUA) contributes in many ways to a sustainable and resilient development of metropolitan regions in general (Zasada, 2011; Aubry, 2012; Barthel and Isendahl, 2013) and in developing countries in particular (Lee et al., 2015; De Zeeuw et al., 2011). Along with the provision of livelihoods, employment, and incomes for farmers and underprivileged urban dwellers (Bryld, 2003; Zezza and Tasciotti, 2010;), PUA is particularly important for regional supply of food and renewable resources (Brinkley, 2012; Paül and McKenzie, 2013; Lee et al., 2015). Further, farmland can provide important ecosystem services for urban areas (Lee et al., 2015), such as micro climate regulation (Lovell, 2010; Ives and Kendall, 2013), management of water resources (Haase and Nuissl, 2007; Pribadi and Vollmer, 2015), flood protection (Kenyon et al., 2008; Weather and Evans, 2009), or prevention of soil erosion (De Graaff et al., 2013; Pribadi and Vollmer, 2015). PUA also contributes to local quality of life and identity as cultural landscapes and areas for local recreation (Yang et al., 2010; Brinkley, 2012; Ives and Kendall, 2013).

However, benefits (and disbenefits) from PUA are narrowly depending on the type and intensity of land use. Some studies of PUA in urban Asia revealed negative environmental impacts of intensive farming practices, particularly for the urban environment due to excessive use of chemical compounds and increasing cropping intensity (Siregar, 2006; Huang et al., 2006; Vagneron, 2007; Khai et al., 2007; Hussain and Hanisch, 2014). Therefore, PUA should be carefully planned and managed to preserve and enhance its benefits for urban and peri-urban areas (Lee et al., 2015; Pribadi and Pauleit, 2015).

Multifunctional agriculture has been proposed as a concept to enhance the multiple benefits of PUA and the capacity of PUA farmers to cope with the multiple peri-urban challenges, e.g. high competition for land and labour, and opportunities, such as proximity to urban consumers (Lovell, 2010; Zasada, 2011, Bausch et al., 2015). According to FAO (2000) multifunctional agriculture refers to multiple agricultural functions to support food security, to enhance positive effects and mitigate negative effects of the environment, to supply products and services for the economic system, and to strengthen the viability of rural communities and livelihoods, culture, and cultural values.

Multifunctional PUA in developing countries is expected to alleviate poverty, generate income and employment, enhance food security, manage a landscape, and curb environmental degradation (De Bon et al., 2010; Zezza and Tasciotti, 2010; De Zeeuw et al., 2011; Pribadi and Pauleit, 2015). Achievement of these aims is a challenging task as farmland in the peri-urban suffers from land conversion and fragmentation (Lee et al., 2015; Pribadi and Pauleit, 2015), soil and water quality degradation (Huang et al., 2006; Vagneron, 2007; Materechera, 2009; Vazhacharickal et al., 2013), insecure land property right (Siregar, 2006; Bersaglio et al., 2014; Rehman et al., 2013), lack of policy support (Aubry et al., 2012; Robineau, 2015), increasing number of landless farmers and the presence of subsistence agriculture (Rehman et al., 2013; Pribadi and Pauleit, 2015), and high competition of labor due to increasing informal non-agricultural jobs in the peri-urban area (Moench and Gwayali, 2008; Rehman et al., 2013; Hussain and Hanisch, 2014).

Studies from Vagneron (2007), Prändl-Zika (2008), and Aubry et al. (2012) showed that the development of multifunctional agriculture at the farm level is capable to increase the profitability and sustainability of PUA. Economic market incentives; regulatory instruments and land use planning; and decision making processes of different actors have been suggested to influence development of multifunctional agriculture (Renting et al. 2009). Still, whether farming successfully adapts to the urban situation and develops multifunctionality critically depends on farmers' decision making (Wilson, 2009; Aubry et al., 2012). Lack of adaptation will leave farmers exposed to the prevailing urban land market pressure, thus the preservation of farming and farmland becomes increasingly difficult and land use zoning efforts ineffective (Paül and McKenzie, 2013; Rustiadi et al., 2013).

A study of PUA in JMA showed that, overall, farmland has persisted during rapid urbanization and enhanced food security at the time of economic crisis in 1998 and 2007, but the shift of agricultural land to upstream areas has increased environmental risks (e.g. flooding and landslides) due to the conversion of forest land (Pribadi and Pauleit, 2015). Reforestation of farmland in upstream areas is hard to be done as farming has become important for supporting incomes, jobs, and food provision for urban and peri-urban dwellers (Pribadi and Pauleit, 2016). Therefore, developing multifunctional PUA offers the most likely approach for maintaining people's livelihoods in the desakota region, on one hand, and enhancing the resilience of JMA to the volatility of food prices and natural hazards, on the other. As finding the right path to develop multifunctional PUA in Asian megacities is hampered by the difficult situation at the farm level, studying the multifunctionality potential of different farming practices in JMA will provide a good reference.

The objective of our paper is to investigate the adaptation behaviour of farmers in response to urbanization processes in JMA and analyze their capability to provide multifunctional benefits in terms of enhanced livelihood through employment and income generation, commodity production, and improving the environment through their farming practices. In particular, the following questions will be addressed: (1) How do farmers adapt to the urban situation? (2) Does this adaptation promote multifunctional farming? (3) Which factors enhance the development of multifunctional agriculture? Particular emphasis will be placed on (1) response to food market opportunities and urban land pressure; (2) capacity to run the farm business; (3) motivation to continue farming; and (4) access to land as the most competitive resource in the peri-urban area.

2 Conceptual Framework

The persistence of PUA is determined by its capacity to adapt to urban and peri-urban settings (Zasada, 2011; Pribadi and Pauleit, 2015). Particularly, it is related to developing products and services which meet the multiple demands of the residents in urban and peri-urban areas (Soy-Massoni et al., 2016). The transition from rural traditional farming to multifunctional farming might differ depending on the particular social, economic, and geographical settings (Renting et al., 2009, Van der Ploeg et al., 2009; Moon 2015), and different agricultural types, farming practices, intensity of land use, and farm location (Zasada, 2011; Aubry et al., 2012, Pribadi and Pauleit, 2015).

According a theory by Wilson (2007, 2008), agricultural multifunctionality can be distinguished into weak and strong multifunctionality. Weak multifunctionality refers to food and fibre production, while strong multifunctionality is characterized by: high environmental sustainability; embeddedness into the local and regional economic system (e.g. providing income, employment, and enhancing viability of rural livelihoods); short food supply chains; low farming intensity (e.g. minimizing chemical inputs, avoiding genetically modified crops, etc.); weak integration into the global capitalist market; high degree of diversification; and high degree of rural populations who see agriculture as a process that goes beyond food and fibre production. Wilson pointed out that the ease of transition is influenced by farming types (e.g. large scale or small scale, full-time or part-time occupation, for hobby or economics purposes, etc.) and farming ownership types (e.g. owner-occupied farms, farms in multi-member ownership, tenant farmers).

In developing countries, the usual prevailing small and economically marginal farms are particularly important to enhance rural livelihoods and local food security (Wilson, 2008; Zezza and Tasciotti, 2010). However, the multifunctional capacity to deliver other benefits, such as environmental or cultural ones is rather limited due to small farm sizes, lack of farm ownership, and low economic turnover (Wilson, 2008).

Nevertheless, Pribadi and Pauleit (2015) showed that farm sizes and economic turnover of PUA are varied depending on different farming types (e.g. horticultural farms, paddy rice farms, other food crops cultivation, etc.) even under the situation of declining farm ownership in JMA. As Wästfelt and Zhang (2016) have argued that the variance of farming types should be considered in developing multifunctional PUA. This leads to the hypothesis that farmers' behavior is different depending on their individual characteristics such as age, education, gender, etc. (Burton, 2014), experience and motivation to farm (McCracken et al., 2015; Hansson et al., 2013), and type of farm ownership, and hence their strategy to deal with limited access to land (Wilson 2007, 2008; Wästfelt and Zhang, 2016).

Based on the hypothesis, the field survey was planned in the catchment area of the Ciliwung watershed. This location was selected as studies from Pribadi and Pauleit (2016), Pribadi and Vollmer (2015), and Vollmer et al. (2016) have shown that PUA in this area has more functions than PUA in other areas of JMA. Questionnaire based interviews were arranged to get data on farmers' behaviour to adapt to urbanization as well as to support multifunctional agriculture.

3 Materials and Methods

3.1 Research Area

The Ciliwung catchment as the case study area (CSA) is located in the southern JMA (Fig. 1). It was dominated by forests (49%) and agricultural land use (35%) in 2012 (Pribadi and Vollmer, 2015). In 2010, only 14% of the working population had an agricultural occupation, whereas about 52% was employed in construction, trade, and tourism sectors, which are mostly informal and intermittent. As in other rapidly growing metropolitan regions in Southeast Asia, the livelihood of people in the peri-urban JMA consists of different income sources. In many cases, farmers in peri-urban JMA also work temporarily in informal urban sectors (Pribadi and Pauleit 2016). Therefore, it is difficult to clearly delineate farmers and workers in the production and service sectors (Moench and Gyawali, 2008).

Due to its farming tradition, agricultural products from the CSA are regionally well-known, especially different types of vegetables such as carrot and spring onion (Eliyani, 2010). Beyond food production, this area also plays a key role in the provision of multiple ecosystem benefits for the overall JMA region, including fresh water supply, flood protection, and recreational services (Pribadi and Vollmer, 2015; Vollmer et al., 2016). Particularly, losing green open spaces in the Ciliwung catchment will largely increase flood risk in Jakarta as the urban core (Rustiadi et al., 2012; Remondi et al., 2016). In the past, natural amenities of this place attracted many urban people to build villas, hotels, and restaurants for leisure activities. In recent years, urban expansion has been limited by the government to improve the hydrological functions of the catchment (Bappeda Kabupaten Bogor, 2014).

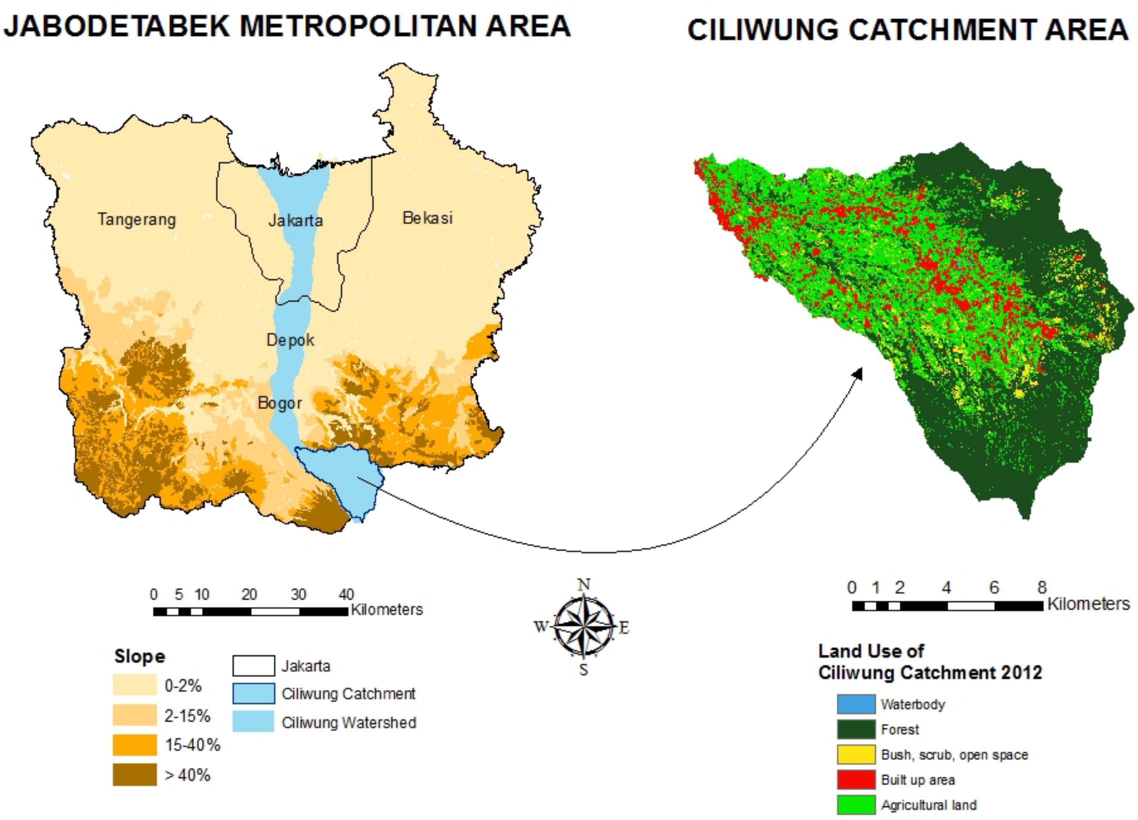

Fig. 1 Map of Jabodetabek Metropolitan Area and Land Use in Ciliwung Catchment Area in 2012

3.2 Sampling and Farm Survey

For the empirical research, questionnaire based interviews with 101 farmers were carried out, and they were selected by a stratified sampling. Landowners who are not farmer were excluded from the interview as they are mostly urban resident of Jakarta that buy a land in the CSA for investment or leisure activities (Firman, 2009). Therefore, decision making on land use mainly depends on the farmers who daily manage the land. Furthermore, interviews were done with male farmers since they play a role in farming decision making as the head of farm households in the CSA. Therefore, this study has a limitation to cover a gender issue. The stratification was based on the distribution of agricultural land use in the upper, central, and lower zones of the CSA. According to previous research (Pribadi and Vollmer, 2015), farmland in the forested upstream part of the CSA is prone to soil erosion, whereas the central area is characterized by both surface water run-off and soil erosion risks. These risks are comparatively low in the northern downstream part. Farmland samples were taken from these three zones and their location was georeferenced to define their position in the catchment (see Fig 2).

The questionnaire was designed to characterize the farmers and their farming activities, and to define their capacity to develop multifunctional PUA. Information about land size, land ownership, and economic turnover of farming, including farmers' characteristics data (age, education, origin, agricultural working time, and capital) were collected as factors that would influence the development of multifunctional PUA. On the other hand, the interviews were aimed to explore whether farmers and their farming activities have sufficient capability to sustain and enhance multifunctional farming benefits. Previous studies showed that PUA in the CSA has the potential to alleviate poverty, generate employment and income, enhance food security, reduce surface run-off and soil erosion (Pribadi and Pauleit, 2016; Pribadi and Vollmer, 2015), and provide natural amenities for recreation (Vollmer et al., 2016). In-depth interviews with farmers were also conducted to get further information about the motivations that shape their farming activities. Interviews were carried out from October until December 2014.

3.3 Statistical Data Analysis

Descriptive statistics were used to analyze the characteristics of farmers and their farming activities, as well as their contribution in supporting multifunctionality. Particularly, input-output of farming activities was analyzed by calculating a cost-benefit ratio (CBR) to asses profitability and sustainability of PUA activities. However, CBR in this study was calculated for one cropping period as commodities and cropping pattern in the CSA depict high variabilities and they change every cropping season depending on fluctuation of commodity market prices.

To identify factors influencing the development of multifunctional agriculture, a Correspondence Analysis (CA) was applied to assess the correlation between farming characteristics and the capacity to develop multifunctional agriculture. CA is an exploratory method used to analyze simple two ways and multiple-way tables containing measures of correspondence between the rows and columns within a crosstabulation table of frequency (StatSoft, 2007). This method fits with our data as association between variables were calculated based on frequency data. Scores in a row and column of each variable would be plotted on two independent axes, and subsequently the proximity between variables describes the level of association between variables.

4. Results

4.1 Farmers and Their Farming Characteristic

Socioeconomic and farm characteristics of the surveyed farms are shown in Table 1. The majority of farmers had low educational level, with only 13% above primary education. Farmers' age ranged from 24 to 84, whereas 77% of them were between 15-64 years old categorized as a working age by the Central Statistic Agency (BPS) of Indonesia. 25% of farmers came from outside JMA. Full-time farmers were dominant. They consisted of farmers who only work in agriculture (Full-time farmer type 1) and farmers who had secondary non-agricultural jobs (Full-time farmer type 2). Horticulture was the most dominant farming type (53%) which was followed by paddy farming (43%). Only a small number of farmers cultivated other food crops (i.e. palawija in Indonesia language), whereas corn and sweet potato were main commodity types of other food crops in the CSA. Most of the farmers did not work on their own land (87%), thus they had an access to land by production sharing, rent a land, working as a property guard (i.e. the property includes houses, gardens, and land), loan money to the landowner (mortgaged land), or illegally opened land in the forest edges (land encroachment).

Table 1 Farmers' Characteristics in the Ciliwung Upstream Area

Characteristics		***Farmers***	
		No.	*in percent (%)*
Education	No_school	11	11
	Primary education (elementary school)	77	76
	Secondary education (highschool)	12	12
	University	1	1
Age	Productive age (15-64)	78	77
	Above productive age (>64)	23	23
Area of origin	Local	76	75
	Immigrant	25	25
Status	Full-time farmer type 1	40	40
	Full-time farmer type 2	33	33
	Part-time	28	28
Agricultural type	Horticulture	54	53
	Paddy	43	43
	Other food crops	4	4
Land access type	Own property	13	13
	Rent	26	26
	Mortgaged land	3	3
	Production-sharing	34	34
	Property guard	22	22
	Land encroachment	3	3

Source : own survey

In general, the majority of the surveyed farmland was cultivated by horticulture (see Fig. 2). Most farmers engaged in horticulture cultivated multiple commodities at the same time or at overlapping consecutive times. Commodities included carrots, tomato, spring onion, chili, cabbage, etc. It can be also seen that most of horticultural land was found in the central and upper area with steeper slopes near forests, whereas farms with other crops were located in the central and lower part of the Ciliwung catchment near settlements (see Fig. 2 and 3).

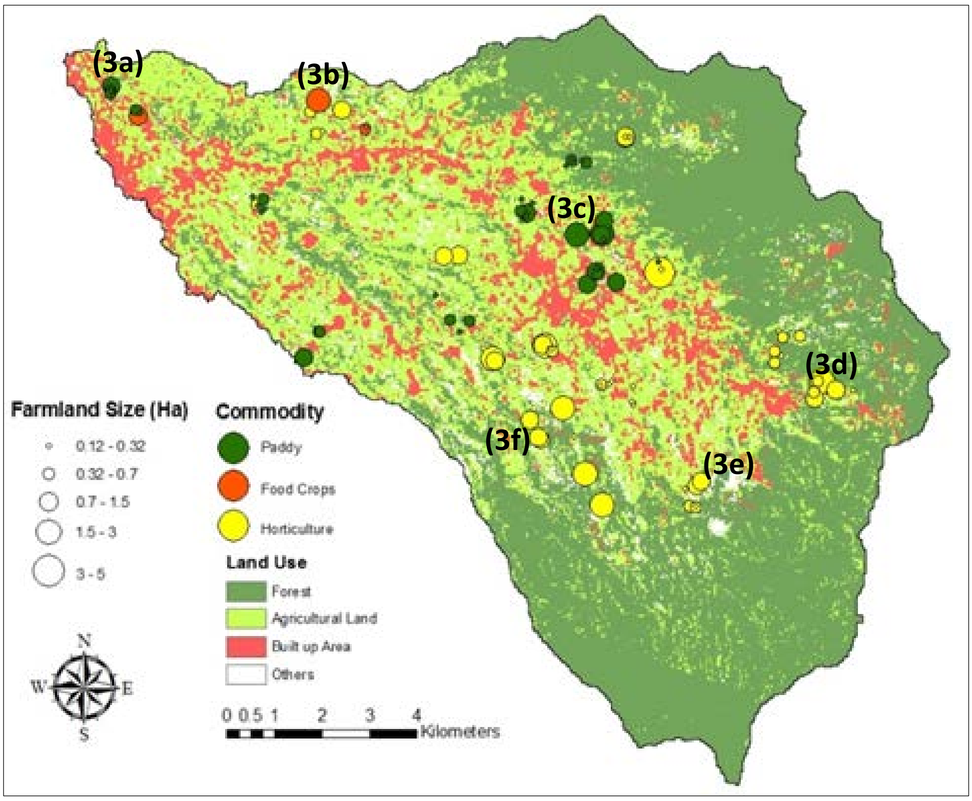

Fig. 2 Distribution of farming samples based on farmland sizes and the locations where Figure 3a-f were taken

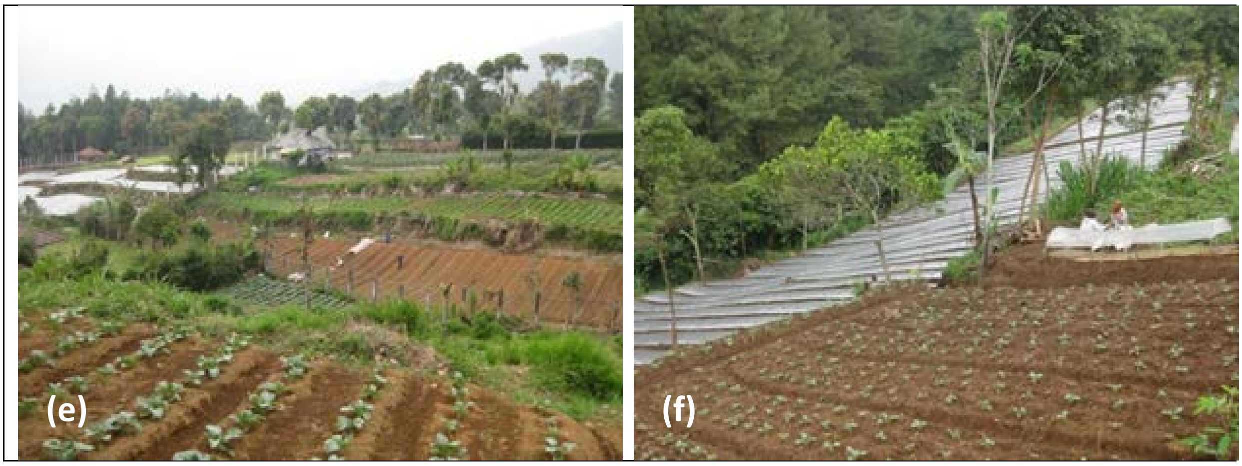

Fig. 3a-f Farm views of paddy field and other food crops in the central and lower area (a, b, c) and horticultural land in the central and upper area (d, e, f)

4.2. Multifunctional Farming Benefits

Income Generation and Employment

The capability of farming activities to generate income is determined by land size, input value, output value, and CBR (see Table 2). Horticulture was cultivated on the smallest to the largest land size. The average of horticultural land per farmer was larger than in paddy fields. Farms with "other food crops" depicted the highest average of land/farmer but this result may not be a representative as the number of samples was small (N=4) and included two large scale farms supported by rich investors from Jakarta.

Table 2 Area, input, output, and CBR differentiated by agricultural type

Agricultural Type	***N***[a]	***Mean***	***Max***	***Min***
Horticultural Farms	54			
Area (ha)		0.81	5.00	0.12
Input Value (USD/ha/season)		2,377	8,894	117
Output Value (USD/ha/season)		9,067	54,718	182
CBR		3.50	14.85	1.00
Labor (man days/ha)		305.82	1587.75	2.19
Paddy rice farms	43			
Area (ha)		0.49	2.50	0.10
Input Value (USD/ha/season)		713	1,578	265
Output Value (USD/ha/season)		763	2,032	251
CBR		1.14	2.62	0.27
Labor (man days/ha)		156.90	348.44	60.00
Farms with other food crops	4			
Area (ha)		1.15	3.00	0.20
Input Value (USD/ha/season)		1,284	1,956	647
Output Value (USD/ha/season)		2,305	3,138	1,178
CBR		2.09	3.94	1.20
Labor (man days/ha)		190.41	356.33	56.88

Source: Author's survey. [a]Number of farmers surveyed;

Note : Exchange rates at the survey time is 1 USD (US Dollar) = 12,747 IDR (Indonesian Rupiah)

Horticulture also encompassed the widest range of input and output values. Small horticultural farmers usually choose carrots that can be easily planted by spreading the seed without any further treatment. On the other hand, small paddy farmers need to put more effort into land tillage. Therefore, in some cases, input into horticulture was less than for paddy rice farming. However, most of horticultural farmers cultivated more valuable commodities in very intensive farming. Consequently, the average of input and output values of horticulture were still much higher than for other crops.

Most of farming activities can generate positive income, especially horticulture, which depicted the highest average CBR. Farms with other food crops had a lower average CBR, with paddy rice ranking at the bottom. Some paddy fields actually had a CBR lower than 1, but farmers can cover it by income from non-agricultural employment to keep their domestic food source.

Horticulture provided larger employment opportunities than other crops as it was more labour intensive. On average, horticulture required almost twice as many man days per ha land than paddy farming. The cultivation of other food crops was also more labour intensive than paddy rice farming. In paddy farming, farmers only required work forces in planting and harvesting periods, whereas horticulture needed labour for the entire cropping period.

Although all of these indicators were calculated for cropping seasons with a different length, the predominant role of horticulture in terms of land size, values of input, output, CBR and employment is obvious. However, as a profitable and capital intensive form of farming, horticultural lands were mostly distributed in central and upper parts of the Ciliwung area which is prone to runoff and soil erosion. Certainly, this should be of concern as land management in this area will affect flood risk in the downstream JMA.

Enhancing Food Security

Most of horticultural farmers sold their produce at the regional market in JMA and they cover a large area of farmland (see Fig. 4a and 4b). Other food crops such as corn and sweet potato were mostly sold locally. Farmers stated that both commodities were mainly sold to street vendors visited by tourists as roasted corn and boiled sweet potato have become well-known products of the CSA. In contrast, paddy rice farmers mostly used their produce for their own consumption as well as for the landowner. Only approximately one-third of paddy rice farmers who occupied a larger farmland sold their produce to the local market. Thus, every farm type tended to contribute to different markets.

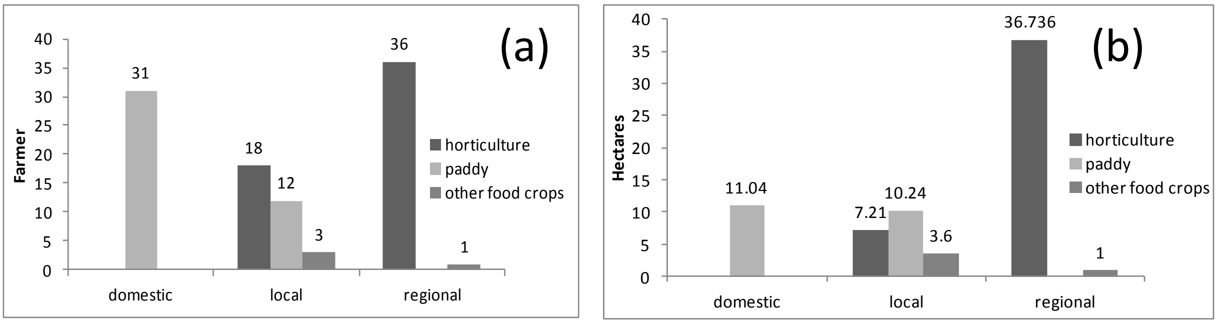

Fig. 4 Market distribution of agricultural product based on number of farmers (a) and size of farmland (b) per farming type

Improving Environmental Quality

Intensive horticultural farming tends to apply chemical fertilizers, pesticides, and herbicides to a larger degree. Our survey showed that on average, horticultural farming spent approximately 398 USD/ha/season, which was much above paddy rice farming where only 103 USD/ha/season were spent. Farms specialized on other food crops also spent a similar amount of money as horticulture (311 USD/ha/season) as some of them were capital intensive farming. Again, despite varying cropping periods, the application of chemical compounds in horticulture was highest.

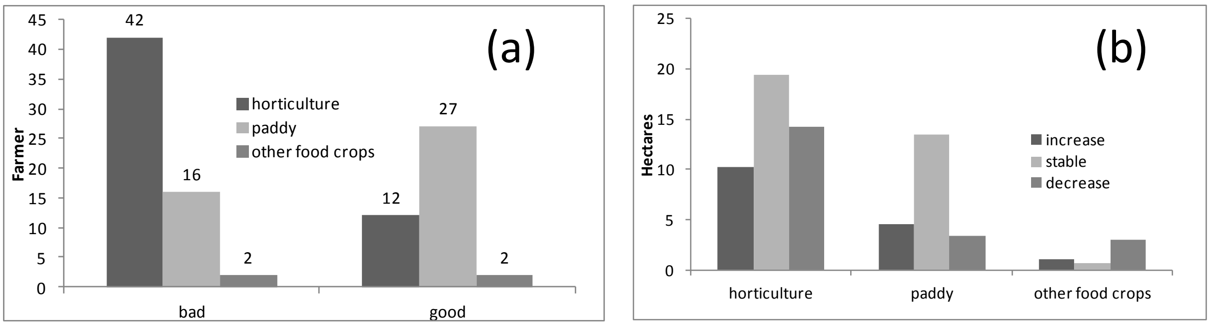

Fig. 5 Adoption of soil and water conservation management (a), and impact on land productivity (b) per farming type

Organic farming as well as soil and water conservation practices were not very frequent. According to interviewees, organic farming was rarely practiced because of knowledge barriers, labor intensity, and limited market size. Moreover, most of horticultural farmers did not apply specific soil and water conservation measures such as mulching, regular plant rotation, temporarily leaving land fallow, organic matter utilization, or cultivation terraces. Therefore, we classified these farms as a bad land management. Some of them even cultivated land continuously on steep slopes not following the contour lines. On the other hand, most of rice farmers applied at least one of those practices, thus being classified as practising good land management (see Fig. 5a). As a consequence, decreasing land productivity occurred in a considerable proportion of horticultural land, whereas land productivity of paddy fields was estimated as being mostly stable (see Fig. 5b). This information was based on farmers' self-assessment of how farmland productivity developed over the last five years.

In addition, the majority of farmers confirmed regular visits by urban tourists. Farmers reported three main tourism activities, which included outdoor recreation in the landscape (e.g. walking, taking pictures, etc.), involving in farming activities, or harvesting and buying agricultural products directly from the field. Based on the average number of recreation activity types, horticultural land provided more activity types than other crops (see Fig 6).

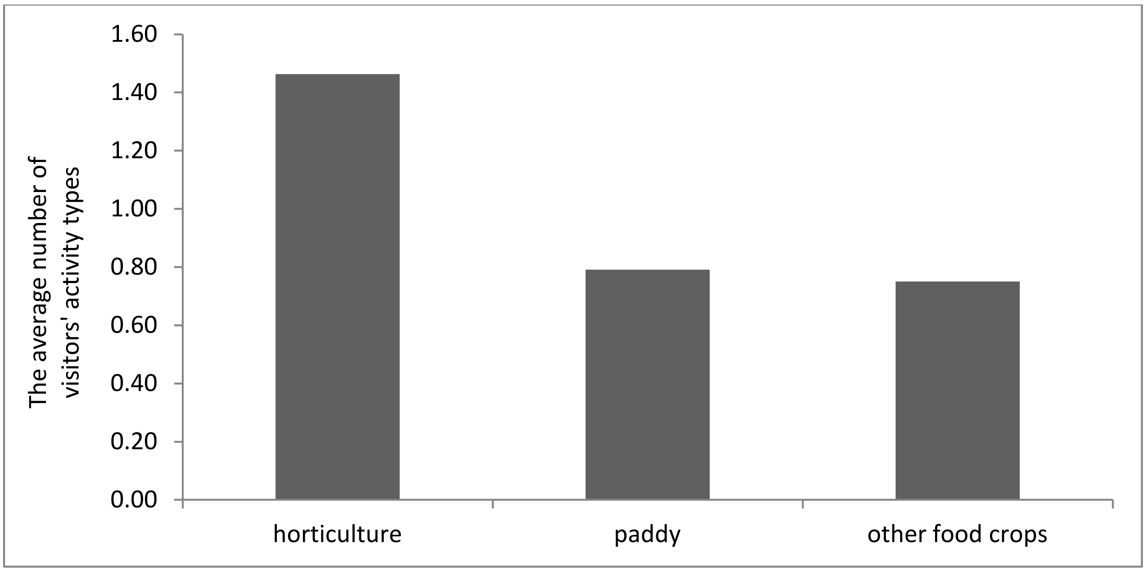

Fig. 6 The average number of visitors' activity types per farming type

4.3. Relationship between farm characteristics and multifunctionality

Based on the above results, the relationship between farm characteristics and capability of different farming types to generate income, create employment, enhance food security, and influence the environmental quality can be further analyzed. CA results in Fig. 7a shows that full-time farmers were closely associated with horticulture whether they have or have not a secondary employment, whereas part-time farmers were closely associated with paddy rice cultivation.

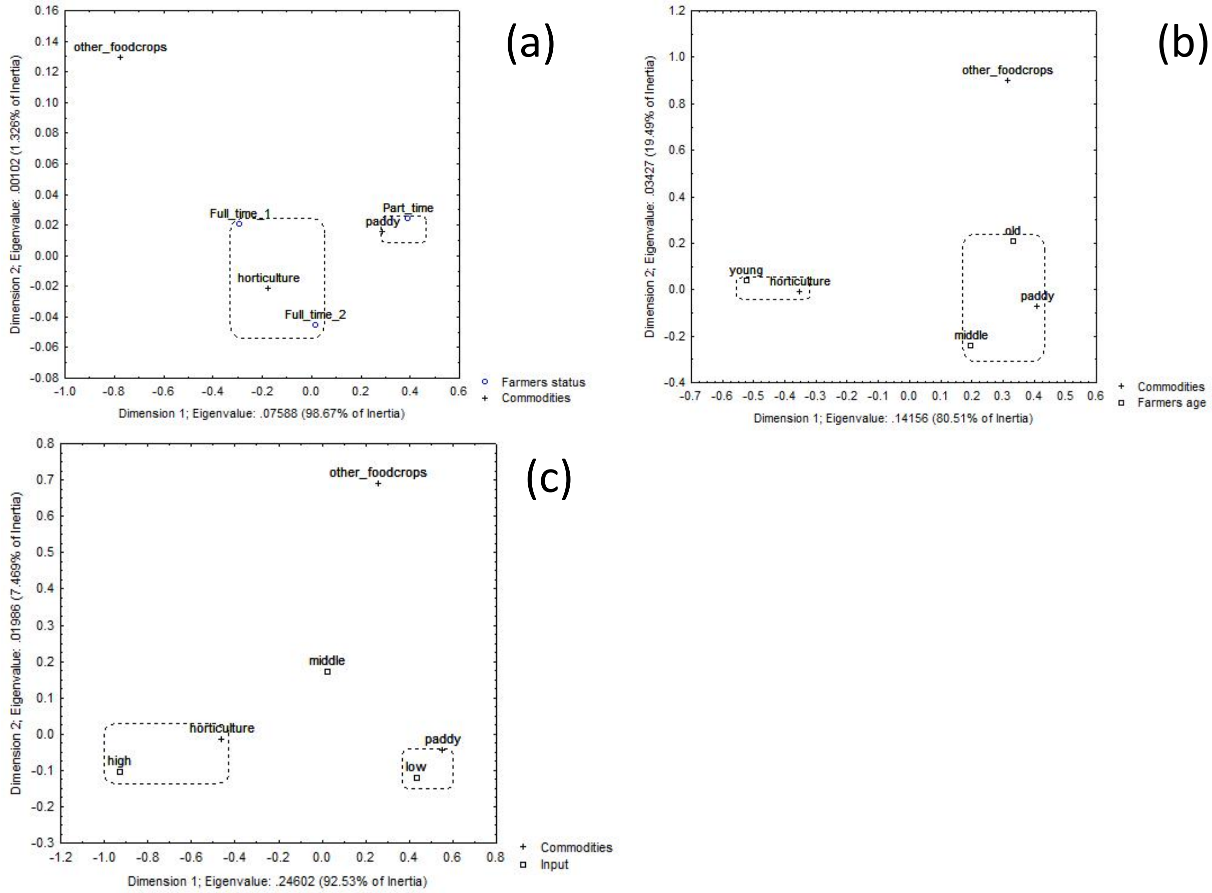

Fig. 7 Relationship between farming types and (a) farmers' status, (b) age, and (c) value of input

Furthermore, Fig. 7b shows that horticulture was more related to younger farmers, whereas paddy fields were more related to older farmers. Horticulture was also more correlated with farmers who had more capital, while paddy cultivation was more correlated with farmers who had limited capital (Fig. 7c). Obviously, horticulture was able to attract full-time, younger, and high-capital farmers, whereas paddy field tended to be cultivated by part-time, older, and low-capital farmers.

Horticulture was also closely associated with a higher CBR, whereas paddy field farming was closely associated with a lower CBR (Fig. 8a). Furthermore, horticulture was also related to a larger market (regional market), whereas paddy field was related to domestic needs (Fig. 8b). These results emphasize the difference between horticultural and paddy rice farms in generating income and market range that has been described. This indicates that horticulture was more driven by an economic motivation, whereas paddy field persisted as subsistence farming.

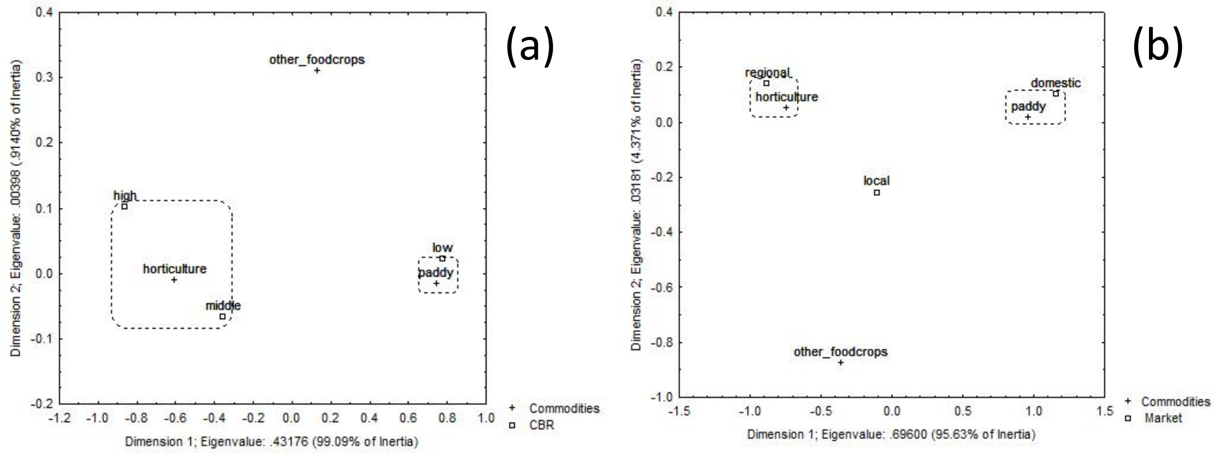

Fig. 8 Relationship between farming types and (a) CBR, and (b) served markets

Another finding of the CA analysis is that horticulture was closely associated with rented land, guarded land, and illegal land. On the other hand, paddy field farming was associated with production-sharing (Fig. 9a). In order to asses farming sustainability on different types of land access, the association between land access types and the risk of farmland conversion as well as land productivity was identified. In this study, the risk of farmland conversion was based on a question whether farmers can continue to farm on their current land for the next five years. Fig. 9b indicates that mortgaged, production-sharing, and land encroachment had unclear relationships with the issue of farmland conversion. Interviewees clearly confirmed that this mainly depended on the landowner’s decision for mortgaged and production-sharing land, or law enforcement for land encroachment. Therefore, the risk of farmland conversion was variable among these farmers. On the other hand, guarded land was closely related to a lower risk of farmland conversion (stable), whereas rented land was closely related to a higher risk of farmland conversion (high).

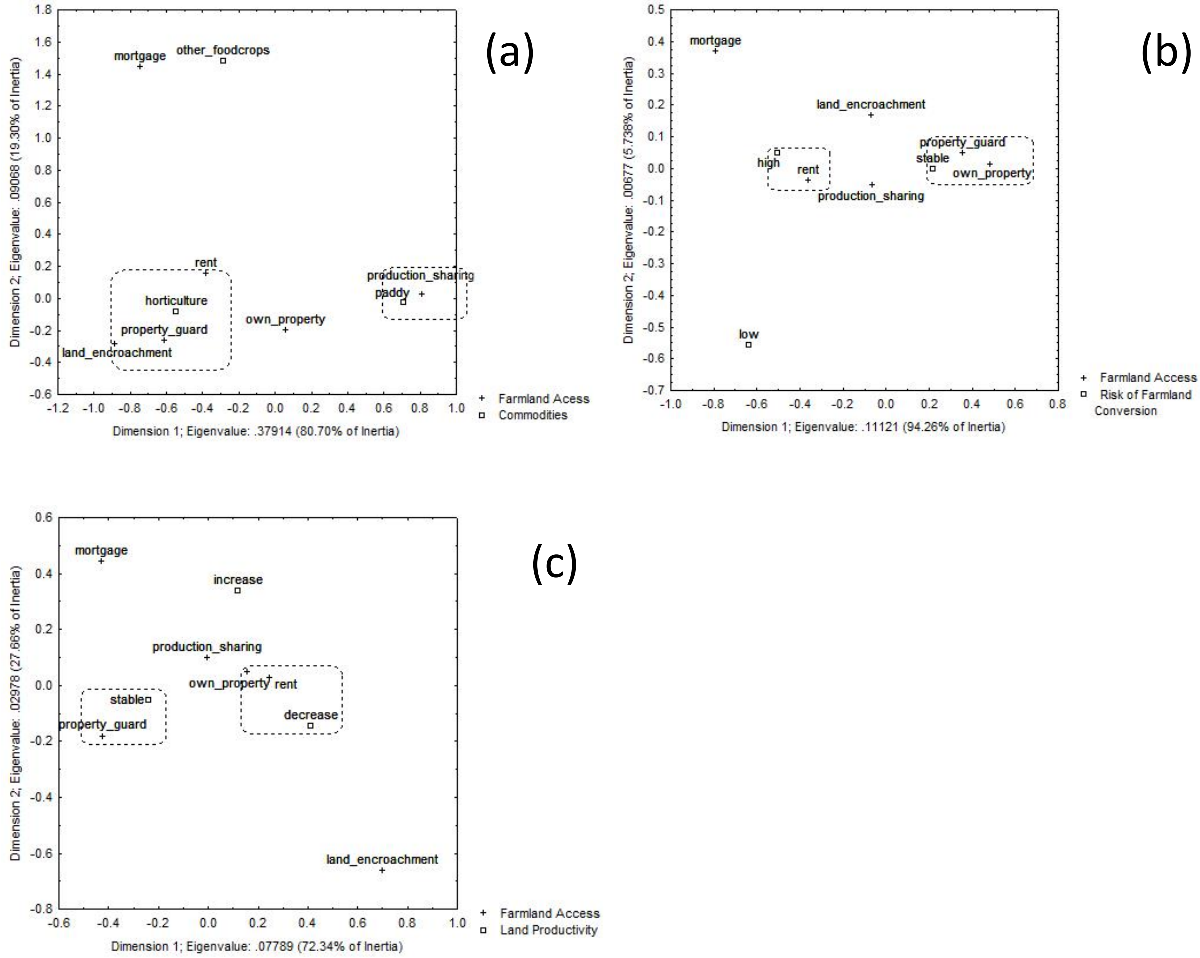

Fig. 9 Relationship between farming access and (a) farming types, (b) risk of farmland conversion, and (c) land productivity

Furthermore, Fig. 9c shows that rented land had a close link with decreasing land productivity, whereas guarded land had a close link with stable land productivity. Again, land productivity was based on farmers’ experience for the last five years. It seems that a higher risk of farmland conversion leads to decreasing land productivity, whereas a lower risk of farmland conversion leads to stable land productivity. Except for the owned-land, a closer connection to lower risk of farmland conversion was parallel with a closer connection to decreasing land productivity as most of these lands were too small and were heavily exploited to get a sufficient yield. Overall, these CA results describe how individual characteristics of farmer’s, their farming motives, and land access types relate to the choices of farming types which have different capacity to generate revenues, supply the different scale of food markets, and affect the environment.

4 Discussion and Conclusions

This study aimed to explore in depth the factors that influence the adaptation of farming to urbanization. Multifunctional farming is suggested as a promising way forward for integrating agriculture into urbanizing regions as it can bring multiple social, economic, and environmental benefits to society (Wilson, 2007, 2008;

Lovell, 2010; Zasada, 2011; Aubry et al., 2012). In particular, the concept of transition towards weak and strong multifunctionality (Wilson, 2007, 2008) was adopted to analyze the respective potentials and limitations of the different farming types present in the case study area (CSA). In order to assess the capacity of farmers to support these multiple functions, we concentrated on farmers' behaviour in response to urbanization, how they manage the farmland, their motivations to farm, and the land tenure situation in the peri-urban zone.

Adaptation of Farming to Urbanization in the Ciliwung Catchment Area

The capacity of farming to adapt to urbanization depends on skills and competences of the farmers and the type of farming activity. Results of our study showed that farmers in the CSA are not well educated, not all are local people, most of them are full-time farmers, and still in the working age. Therefore, despite their low education, they still have a potential to adapt to urbanization as most of them are in a range of productive ages, highly motivated, and work full time in agriculture.

Horticultural and paddy fields have become two dominant farming types. Not all farming activities are small scale (less than 0.5 ha according to BPS 2013), even most of the horticultural farms occupy larger areas. In addition, a majority of farmers work on land owned by urban residents with an interest in non-productive, leisure-oriented activities (Firman, 2009). Therefore, they have access to land mostly by sharing the harvest with the landowner, rent a land, or they work as a property guard. It indicates that farmers in CSA have a strong motivation to continue farming, even under the situation of lacking land ownership.

The two dominant farming types (horticulture and paddy rice farms) respond differently to urbanization. Paddy rice farms have become smaller and fragmented due to urban encroachment. Land use change analysis from 1983 to 2012 showed that 50% of paddy fields in the CSA had been converted to settlements (Pribadi and Vollmer, 2015). Consequently, paddy rice farmers have been increasingly forced to find additional sources of income. Fortunately, urbanization provides them with new job opportunities in informal sectors such as construction workers, parking attendants, food street vendors, food peddlers, motorcycle taxis, etc. (Konsorsium Penyelamatan Kawasan Puncak, 2014). However, they still continue farming to secure their domestic food source as their informal jobs are non-permanent.

Horticultural farms, on the other hand, have been expanding and they have moved to larger tracts of farmland further away from the settlements and penetrated the forest land. In the CSA, losses of dryland agriculture (a land use type dominated by horticulture) caused by urban development have been compensated by almost 5 times the area from 1983 to 2012 (Pribadi and Vollmer, 2015) at the expense of other farming types and forested land. Instead of seeing urbanization as a threat, horticultural farmers take advantage of the proximity to the growing urban market. Farmers within the JMA benefit from enhanced access to information on fluctuating regional market prices, access to different intermediary brokers, and shorter distances to the market. However, while being economically adapted to the urban situation, due to a higher intensity of production, horticulture increases environmental stresses in areas prone to soil erosion and surface runoff, thus amplifying flood risk in the downstream JMA.

The two dominant farming types also differ in the management of farmland. Paddy rice farmers tend to reduce farming costs by cultivating their land only twice a year; rarely using fertilizers, pesticides, or herbicides; and farming is mainly done by themselves and their family. Still, the harvest is enough for fulfilling family needs on rice for a year. Furthermore, low intensive farming can keep land productivity (see Fig 5b). Conversely, horticultural farmers invest much more capital. In order to deal with the perishable nature of the produce and the complexity of the vast JMA food market which involves many middlemen, traders, and suppliers, the farmers tend to cultivate a variety of crops to reduce price dependency on individual crop. They also respond to the market situation by flexibly changing cultivated crop types. In addition, horticultural farmers also use excessively chemical compounds to reduce the risks of losing their investment (see also Hussain and Hanisch, 2014). As it is a very intensive type of farming, more field workers are employed.

Obviously, there are two different motives that make farmers in the CSA continue to farm. For paddy rice farmers, the motive is to secure their domestic food source as they become economically vulnerable due to urbanization. Thus, most of paddy fields persist as subsistence farming which are mostly run by older, part-time, and relatively poor farmers. On the other hand, horticultural farmers receive higher economic revenues from selling products to the nearby urban market. They are mostly run by younger, full-time, and capital intensive farmers.

Lack of land ownership is a major problem for the sustainability of farming. Most paddy rice farmers cultivate on land close to where they are living as this land previously belonged to them. During the peak periods of urbanization in the 1990's, many farmers sold their land as it was regarded more profitable than utilizing it for paddy fields (Firman, 2000). They can continue farming by sharing the harvest with the landowner. Depending on the landowner, paddy fields are at risk of being converted to settlement. Insecure farm ownership has less impact on land productivity as paddy fields in the CSA have low farming intensity.

On the other hand, horticultural farmers have access to larger tracts of land, mostly by renting the land or becoming a property guard of the landlord. Horticultural farms on rented land show more exploitative behaviour. The relationship between farmers and landowner is purely business based on a short-term contract of one or two years duration. The contract can be ended whenever the landowner wants to use the land or rent it to another farmer. Therefore, the tenant farmers exploit the land to quickly return their cost of investment. Conversely, horticultural farms on the land guarded by farmers exhibit farming practices that are more concerned about environmental issues. The relationship between farmers and landowner is more personal, long-term, and based on mutual trust, thus it reduces the risk of farmland conversion. As a result, farmers feel responsible to maintain the land and its productivity in order to secure long-term farming activities.

Overall, the results show that paddy rice farming faces more pressure from urbanization due to the comparatively low farming intensity, subsistence farming, and insecure land ownership. However, it is an important food source for the poor. Moreover, paddy fields are important to contain runoff in CSA (Pribadi and Vollmer, 2015; see also Matsuno et al., 2006; Lee et al., 2015) and have a potential to attract urban visitors. On the other hand, farming types such as horticulture have higher farming intensity and are revenue oriented can adapt more easily to urbanization. The latter can generate valuable income, employment, and food supply for urban and periurban dwellers, as well as support outdoor recreational activities, but it causes negative environmental impacts.

Multifunctionality of Farming in the Ciliwung Catchment Area

Regarding Wilson's (2008) criteria of strong multifunctional agriculture, paddy rice and horticultural farms show different degrees of multifunctionality. Paddy rice farms are embedded in local and regional socio-ecological systems as a food source for the poor and recreational areas for urban visitors, as well as have low farming intensity and higher environmental sustainability. However, they have low embededness in regional economy and have a low degree of diversification. On the other hand, horticultural farms have stronger embeddedness to local and regional economy (income and employment generation), supply urban food demand, and attract urban visitors. However, they have high farming intensity (excessive use of inorganic fertilizer, pesticides, herbicides) and lower environmental sustainability. Moreover, both farming activities are also not being supported by public understanding of the multifunctional benefits they can generate beyond food and fibre production, thus farmland is not assigned a role in the future development of JMA (Hudalah and Firman, 2012; Pribadi and Pauleit, 2015). Consequently, lack of strong multifunctionality at the farm level will cause that paddy rice farms are left by the young generation due to low benefit of farming. On the other hand, horticultural farms cannot be sustained due to declining land productivity.

Wilson (2007, 2008) argued that efforts to reach strong multifunctionality are hampered by small farm sizes, lack of land ownership, and low economic turnover. In the CSA, this only occurred in paddy rice farms which are small scale, have a high dependency on the landowner, and a low economic turnover as the farmers are older, part-time, less capital, and less economic motive. In contrast, farmers who are young, full-time, having more capital, and economically-motivated can have an access to large tracts of land and create high economic turnover through horticultural farms.

The study clearly showed that farmers' individual decision making is of more importance for urban adaptation. Decision making is particularly influenced by: (1) the individual capacity of the farmer (age, working time allocation, and capital), (2) farmers' motive (economic revenue oriented or subsistence), and (3) the land tenure situation (secure or insecure).

These findings confirm other studies which highlight the role of farm household characteristics (e.g. age, capital, motivation, etc.) to determine farmers' decision making (Rodríguez-Entrena and Arriaza, 2013; Villanueva et al., 2015). Farmers even accept to take a risk of insecure land ownership, although it will burden them in running the farm. Therefore, based on the three factors highlighted before, three interrelated strategies can be suggested to strengthen multifunctional agriculture in the CSA.

First, increasing farmers' capacity for developing profitable activities on and off the farm will promote sustainability of farming as well as push the farmers to continually improve their skill and knowledge to manage farmland. For paddy rice farmers, some programs should be designed to enhance their capability to create other farm business such as tourism or educational farming as their farms are located close to settlements, public, and recreational centers. Horticultural farmers should be supported to adopt conservation practices and organic agriculture due to increasing concern for better quality of the catchment area (BPDAS Citarum-Ciliwung, 2011; BBWS Ciliwung-Cisadane, 2012), as well as to satisfy growing urban demands for fresh and healthy commodities in the forthcoming years (Indonesia Business Daily, 2016). Besides, their capability to take a benefit from urban visitors should be enhanced through direct marketing, developing a variety of products, etc (see also Wästfelt and Zhang, 2016).

Second, the offer of non-commodity products and services of farmland should be broadened. These may include goods and services for non-food markets such as tourism, education, etc., and supporting non-marketable public benefits such as food security, local economic development, maintaining environmental quality, etc. (Renting et al., 2009). As results have shown, there is a potential within the CSA to develop agro-tourism activities, but lack of farmers' capacity and limited right to manage the land hinder their opportunity to generate income from urban visitors. Furthermore, non-marketable public benefit of farmland is undeveloped as the multiple roles of PUA are still not considered in urban policies of JMA (Pribadi and Pauleit, 2015). Therefore, policies need to be designed for supporting the generation of social and environmental benefits provided by the particular farmland (Broch et al., 2013). These policies will not only motivate farmers to manage their farm better, but also build a collective understanding about the importance of PUA for public benefits.

Third, securing farmers' access to land will enable the farmers to plan their farming activities in the long term perspective. Government should facilitate and legalize long-term agreement between farmers with the landowner. Thus, the landowner will get an assurance that their property will be managed well, while the farmers can arrange their farming activities in the long run. This also gives an opportunity for the government to design long and mid-term programs for developing agricultural infrastructures (e.g. irrigation, farm roads, agricultural terracing, etc.), and enhancing farmers' capacity to manage farmland (e.g training, technical assistance, introducing agro-technology, etc.). A longer-term planning horizon is needed to diversify farming business and to implement sustainable farming practices, particularly in peri-urban zones which have a high risk of social, economic, and environmental change (Adelaja et al., 2011). This strategy will help the implementation of spatial planning policies to protect agricultural land as well as improving agricultural productivity (Leitgeb et al., 2015), and increase the quality of the CSA as a catchment area.

The implementation of these three strategies would promote the transition of farming towards strong multifunctional agriculture. Results from the study suggest that increasing farmers' capacity, developing non-commodities products and services of agriculture, and securing land access will lead to higher environmental sustainability, lower farming intensity (i.e. reducing use of inorganic inputs in horticulture) and higher degree of diversification. Moreover, it may lead to a higher degree of public understanding about agriculture which is not only important for food and fibre production but also for social-ecological benefits. Thus, the persistence of farmland in CSA in particular, and peri-urban areas in general, would be enhanced.

This research was based on interviews with farmers in a certain area of peri-urban JMA. Further research needs to be done in a wider area of PUA land in JMA that probably has different characteristics. The results provide a better understanding about rural-traditional farming adaptation to urbanization and its transition towards strong multifunctional PUA that could be used as a reference for PUA management in Asian megacities. Some important elements for strategies to promote PUA could be identified. Still, further policy research is needed to design regulations, programs, and allocate public budgets that could support strategies to develop strong multifunctional PUA as a means to manage urban-rural landscapes in desakota regions of Asian megacities.

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