With increased awareness of the importance of land use change at both local and regional scales within watershed-based planning, the study of land use analysis has become the focus of several international scientific endeavors. Since land use change has become a major issue in this century due to global urbanization, the study of watershed-based land use analysis will play an important role in a sustainable future. This paper undertakes a comprehensive review of watershed-based land use analysis to clarify the research trends in this area, including basic tools, factors, methodologies, study regions, scales and areas. Land use detection methods, land use modeling and thresholds in watershed delineation were identified as the fundamental tools, while land use policies, water quality, surface runoff, flooding control, land use suitability and land allocation analysis, and landscape structure were identified as the main factors in watershed-based land use planning.

Key Words: land use analysis, watershed, local and regional scale, watershed-based land use planning

1. INTRODUCTION

Land use change is a major issue for this century, and urbanization is considered to be one of the dominant forms of land use change in terms of increasing surface runoff, impervious cover, and non-point source (NPS) pollution, which are accompanied by water pollution components\(^1\),\(^2\). Consequently, it causes urban flooding and degradation of water quality and the natural environment, leading to further changes in land use patterns.

Watershed-level planning is inherently concerned with land use issues and their impact on watershed interests, such as stream quality and biological diversity. Watersheds have been used as physical, biological, social, economic, and political units for the planning and implementation of land management activities\(^3\). In the United States, the use of watersheds as planning units originated from defining the best hydrological planning units for land, water, and ecosystem management, then defining governmental boundaries based on watersheds, and finally delineating the boundaries of district planning based on watersheds\(^4\). For example, in New York, a watershed management agreement was signed in 1997 to protect the quality of drinking water while promoting environmental sustainability compatible with economic development\(^5\). Japan has based planning for ecosystems, cultural landscapes, and disaster prevention on the watershed unit; it has also introduced watershed-based planning in the master plans for parks and open space in some municipalities\(^6\). Therefore, for city and regional planning, the watershed can be considered as a reference even though its boundaries do not necessarily coincide with the administrative boundaries.

In watershed-based research, the study of land use is considered to be one of the most prominent issues. Many studies have focused on the influences and impacts of land use practices due to urban development, which have a major impact on the natural environment and consequentially on the watershed. These studies have been discussed widely in the fields of hydrology, water resource management, environmental management, agriculture, geography, geology, land use, landscape, green space, and disaster prevention planning. They differ in their purposes, methodologies, available data, and applications, since the nature of land use analysis is dependent on many driving forces, especially the in-
teraction between human activities and natural resources. Therefore, this multifaceted issue requires a multidisciplinary approach to resolve its associated problems, which are introduced in this paper.

As the rate of global urbanization is constantly increasing, and the study of watershed-based land use analysis is broad and deals with complicated issues, it is essential to clarify research trends in this realm. Therefore, the aim of this paper is to: (1) identify the research trends of basic tools, and (2) identify the research trends of the factors, methodologies, study regions, scales and areas, and the relationship of these factors in watershed-based land use analysis, which can be used for better future planning and research.

2. RESEARCH METHODOLOGIES AND PROCESS

(1) Definition of catchment, sub-watershed, watershed, river basin, and drainage area

A catchment is a land area where all surface water (rain, melting snow or ice) drains into a common outlet, while a sub-watershed is composed of two or more catchments; a watershed is composed of many catchments and sub-watersheds.

The term 'river basin' is defined as an area of land drained by a river or its tributaries.

A drainage area is the total surface area, upstream of an outlet of a stream, where water from rain, snowmelt, ice or irrigation not absorbed into the ground flows over the ground surface and back into streams, and finally flows into the outlet.

(2) Selection of target academic papers

In the selection process for the academic papers targeted in this study, we used web search engines and publishers’ websites, input keywords, and criteria for selecting target academic papers.

The selection process for target academic papers is shown in Fig. 1. First, 15 combinations of two keyword terms were inputted into web search engines and publishers’ websites based on the criteria shown. The obtained watershed-based papers were concerned mainly with three fields: landscape, ecological environment, and land use, with dates ranging from 1977 to 2015. Second, the target papers were filtered and selected for the studies related to watershed-based land use analysis, excluding the two other fields. The dates of the resulting papers ranged from 1991 to 2015, as shown in Table 1. These papers come from international journals and conference papers and various academic journal publishers. These publishers covered almost the whole globe including Europe, Asia, and North America, which shows that various publishers were involved in the academic paper selection process. The study regions were mainly defined according to the continents; these studies have been carried out in Asia, Europe, North America, South America, Africa, Australia, and Oceania.

(3) Historical review of the target academic papers

Watershed-based studies, which have received far more attention within the biological and physical sciences than the social science framework, have long been used by researchers in landscape as well as ecological and environmental management studies.

Once filtered, the dates of the selected papers began in 1991. Watershed-based land use analysis became prominent during the 1990s, when many watershed geographical information (GIS) applications were developed7) and growing concerns about

| Web Search Engines: Google Scholar, Scopus, Web of Science, J-Stage | ScienceDirect, ASCE library, Wiley Online Library |
|---------------------------------------------------------------|--------------------------------------------------|
| Input two keyword terms in the web search engine=a,b | |
| (0<i≤5; 0<j≤3) | b1. Based on watershed |
| a1. Land use | b2. At a watershed scale |
| a2. Land use analysis | b3. At watershed level planning |
| a3. Land use planning | |
| a4. Land use change | |
| a5. Land cover | |
| Note: No limitation to the publishing year |

Criteria for academic paper selection
1. Based on the background of each academic paper relating to the issues of urban development, urban expansion, urbanization and its associated influences, impacts and consequences in terms of various research fields.
2. Selecting the related papers in the references of each academic paper in 1.

Selection of academic papers
Around 70 academic papers including landscape, environmental ecology and land use, which are based on watersheds, were identified, with the publishing years ranging from 1977 to 2015.

Criteria for target academic papers selection
Filtered and selected for papers mainly related to watershed-based land use analysis 55/70

Note: 15 of the 70 papers are not referred to in the references.

Fig. 1 Target academic paper selection process.
urban development’s effects on the natural environment began prompting efforts to find more sustainable solutions to the problems arising from the built environment.

(4) Contents of this study

Section 3 examines the general trends in the target academic papers. All target academic papers were categorized based on publisher, characteristics of study regions, and research fields.

Section 4 covers research trends in the basic tools applied in watershed-based land use analysis. This section discusses basic tools including land use detection methods, land use modeling and thresholds in the watershed delineation process.

Section 5 discusses research trends in the factors used in watershed-based land use analysis. In this section, target academic papers were summarized based on background, purpose, target watershed scale, data type, methodology, findings, limitations, and future research. These factors were identified based on the research purposes of each summarized paper and then grouped in order to clarify methodologies, study region, area, scale, and the relationship of these factors in watershed-based land use analysis in different research fields.

3. GENERAL TRENDS IN THE TARGET ACADEMIC PAPERS

A total of 55 target academic papers were categorized according to publisher, characteristics of the study region, research field and journal name, with the publishing year of each target academic paper, as shown in Figs. 2, 3, and 4 respectively.

Among the target academic papers, as shown in Fig. 4, four main research fields were defined: (1) environment and management, (2) hydrology, (3) planning and development, and (4) remote sensing, GIS applications, and others. Figures 2 and 3 show trends in the study regions and publishing years. Before 2002, few papers were defined in Asia; however, from 2003 a fluctuation in the number of studies seems to have taken place in Asia.
Table 1 Publisher and journal name of target academic papers.

| Publishers | Journal name (total papers) (publishing year of target academic paper) |
|------------|-------------------------------------------------------------------------|
| **Elsevier** | Agriculture, Ecosystems and Environment (2) (2001; 2003)  
CATENA (1) (2003)  
Computers & Geosciences (1) (2010)  
Environment International (1) (1997)  
Journal of Environmental Management (2) (2001; 2005)  
Journal of Hydrology (1) (2002)  
Land Use Policy (1) (1995)  
Landscape and Urban Planning (6) (2000-2015)  
Physics and Chemistry of the Earth (1) (2001)  
Procedia Environmental Sciences (1) (2011)  
Science of the Total Environment (1) (2015)  
The Egyptian Journal of Remote Sensing and Space Sciences (1) (2015) |
| **John Wiley & Sons** | Hydrological Processes (2) (1991; 2006) |
| **Springer** | Environmental Management (2) (2000; 2009)  
Environmental Monitoring and Assessment (2) (2006; 2011)  
Sustainability Science (1) (2014) |
| **American Society of Civil Engineering (ASCE)** | Journal of Hydrologic Engineering (1) (2013)  
Journal of Urban Planning and Development (2) (2014)  
Journal of Water Resources Planning and Management (1) (1995) |
| **American Water Resource Association (AWRA)** | Journal of the American Water Resource Association (JAWRA) (1) (2004) |
| **Association of American Geographers** | Middle States Geographer (1) (2007) |
| **Japan Society of Civil Engineering (JSCE)** | Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering) (1) (2012) |
| **Japanese Institute of Landscape Architecture** | Journal of The Japanese Institute of Landscape Architecture (6) (2002; 2012) |
| **Architecture Institute of Japan (AIJ)** | Journal of Architecture and Planning (2) (2007; 2009) |
| **Ecology and Civil Engineering (ECES)** | Ecology and Civil Engineering (1) (2003) |
| **GIS Association of Japan** | Theory and Applications of GIS (1) (2010) |
| **Japan Society of Erosion Control Engineering (JSECE)** | Journal of the Japan Society of Erosion Control Engineering (1) (2005) |
| **Japan Society of Tropical Ecology (JASTE)** | Tropics (2) (2004; 2011) |
| **Scientific Research, International Lake Environment Committee Foundation (ILEC)** | Journal of Lakes & Reservoirs: Research and Management (1) (2002) |
| **International Research Operation in Sciences & Social Sciences (IROSSS)** | International Journal of Advancement in Remote Sensing, GIS and Geography (1) (2014) |
| **Japan Society of Geoinformatics (JSGI)** | Geoinformatics (1) (2002) |
| **Scientific Research** | Journal of Geographic Information System (1) (2012) |
| **Others** | Asia Conference of Remote Sensing (1) (2010)  
The International Symposium on Cartography in Internet and Ubiquitous Environments (1) (2015)  
Environmental Design Research (1) (2012)  
The 15th Science Council of Asia Conference and International Symposium (1) (2015)  
World Water and Environmental Resources Congress (1) (2001) |
4. RESEARCH TRENDS IN BASIC TOOLS

In the study of watershed-based land use analysis, land use detection methods, land use modeling, and watershed delineation methods are considered basic tools, and are applied widely by researchers using watersheds as the planning unit.

(1) Trends in watershed-based land use detection and modeling

The progressive worsening of urban environments, and the destruction of ecosystems due to the rapid pace of urban development, have led to awareness of the important role of land use and land cover in overcoming those problems. Therefore, it is essential to understand the trends related to the study of land use applied at the watershed scale. Among the 55 target academic papers, watershed-based land use analysis has been carried out in two forms: land use detection methods and land use modeling.

a) Trends in watershed-based land use detection methods

Rapid development of computer technology makes it possible for both scientific communities and scholars to make use of databases such as Quickbird, RapidEye and Landsat, which provide data at very high, high, and medium spatial resolution, respectively. These databases are used to carry out land use and land cover analysis with the integration of geographical information systems for understanding and defining land use and land cover dynamics, understanding land use change, and predicting land use in the future. Many studies have shown that studies of land use detection have made extensive use of satellite imaging such as the Landsat Multispectral Scanner System (MSS) and Landsat Thematic Mapper (TM), with remote sensing software ERDAS IMAGINE, while a few studies also applied image-processing software IDRISI and Geographical Information System (GIS) with image processing for the detection of land use through Landsat data with six important steps in image classification. However, in detecting land use using remote sensing data, there are some shortcomings for tropical areas, where the cloud cover is high. Some studies have developed a method to overcome these shortcomings. In addition to land use detection by remote sensing, land use detection may also be conducted with land use data sheets and historical geographical maps using the PLUR program.

In brief, remote sensing and GIS are considered essential technologies, which enable temporal analysis and qualification of spatial phenomena with less time and low cost.

b) Trends in watershed-based land use modeling

Watershed-based land use modeling has proved to be a useful tool for land use scenarios studies, as it provides not only the spatial distribution of land use based on the basic spatial data of land use and topography, but also the basic data for calculating landscape pattern metrics and hydrological components. It also provides useful information about the possible environmental impacts of future urbanization.

In watershed-based land use analysis, six types of land use modeling have frequently been applied. The first model, Conversion of Land Use and Its Effects (CLUE-s), is based on an empirical model measuring the conversion of land use and its effects combined with other models for an integrated approach to simulate and evaluate land use changes, landscape patterns, and their effects on hydrological
processes at the watershed level\textsuperscript{22}.

The second model, the Land Use Change Modeling Kit (LUCK), is an approach to scenario generation using a grid-based discretization mode at catchment scale. It presents the spatial distribution of land use types in a landscape based on an evaluation of the characteristics of each grid, as well as on its neighborhood relationship. It is used for land use scenario generation providing a spatially distributed specification of land use changes in meso-scale catchments\textsuperscript{25}.

The third model, SLEUTH, is an urban growth model with cellular automation. It is used to estimate present and future surface runoff and peak discharge in small- and medium-sized urban watersheds through land use information derived from satellite images\textsuperscript{11}.

The fourth model, Cellular Automata (CA), is a well-known land use change approach used among peer-reviewed journals. It models urban sprawl by simulating complex dynamic processes through relatively simple rules, and can be applied for urban growth simulation and predicting the extent of an urban area\textsuperscript{26}.

The fifth model, Land Use Transformation (LTM), is applied for forecasting and assessment of the impact of land use changes on runoff, as well as long-term runoff and NPS pollution\textsuperscript{24, 27, 28, 29}.

The sixth model, Markov, is applied for predicting land use structure in the watershed\textsuperscript{40}.

All land use modeling can be categorized based on eight core methodologies: Markov Chains, Economic-Based, Statistical Analysis, Cellular Automata (CA), Geographic-Based, Artificial Neural Network, Agent-Based, and Integration Modeling\textsuperscript{30}. Not all of these methodologies are applicable to watershed-based land use planning. The relationship between the major methodologies and watershed-based land use modeling is shown in Fig. 5.

(2) Trends in threshold definition methods in the watershed delineation process

Due to advances in desktop GIS capabilities, programming languages, and data availability, many watershed geographical information system (GIS)-based applications have been developed since the early 1990s. Hydrological modeling is a well-developed technology that has been widely applied with GIS in various studies, in particular those related to geomorphology, soil science, hydrology, and land use planning\textsuperscript{31}. In hydrological modeling, Digital Elevation Models (DEMs) are important and useful sources for automatically generating the flow direction, flow accumulation, stream direction, drainage line, catchment, sub-watershed, and watersheds. This system depends mainly on the input of thresholds in order to identify watersheds.

In brief, the smaller the chosen threshold, the more catchments it produces, which makes the channel complicated. However, the appropriate and reasonable stream threshold for defining the watershed remains unclear, since the only way to determine a reasonable stream threshold is by trial and error, which consumes much time\textsuperscript{41}.

In watershed-based planning, the chosen threshold, which identifies the watershed unit of planning, influences and impacts the planning process. Thus, threshold issues should be discussed clearly in the planning process. Among the 55 target academic papers, two types of watersheds were defined from the planning perspective: rural watersheds and urban watersheds.

a) Rural watersheds

Rural watersheds refer to original terrain where the natural topography conditions such as landform, surface shape, and the natural drainage pattern and network are not superimposed by infrastructure, such as streets, roads, and buildings. Rural watershed delineation, drainage pattern, and flow calculation have been shown to be capable of being automatically generated through digital terrain models. Of the computer-based terrain representations, grid algorithms such as DEMs were found to be better at defining large rural watersheds than the other two methods, Triangle Irregular Network (TIN) and Contours\textsuperscript{32}. Eight types of applications have been used for watershed-based land use studies. These applications are: GIS-ARC/INFO\textsuperscript{33, 34}, GIS-GRASS\textsuperscript{35}, TNTmips\textsuperscript{36, 37}, GIS-Hydrological Modeling\textsuperscript{38, 39, 40, 41, 42}, Terrain Processing in ArcHydro\textsuperscript{3, 44}, and WinGrid system\textsuperscript{45}. In addition, certain researchers manually identified the watershed boundary by using topographical maps\textsuperscript{12, 45}. The majority of researchers tended to use the hydrological modeling tool in GIS to delineate the stream network. However, the threshold for defining stream
network analysis was not discussed widely in the existing literature, though certain researchers were interested in discussing the identified thresholds in rural watersheds\(^{33, 39, 40, 41, 43, 46, 47}\).

Five types of existing threshold-defined methods were identified in the target academic papers. The first method was applied using a trial threshold value and used natural topography as the reference for studies carried out to evaluate the green space environment in small watersheds, based on the water cycle\(^{40, 41, 46}\).

The second method involved trialing threshold values for obtaining corresponding average area of watersheds. Threshold was decided on the basis of comparing between the total average areas of administrative boundary with obtained average area of watersheds, for basic studies of land use planning\(^{38}\).

The third method, constant threshold, was defined according to flow accumulation automatically generated by using GIS. This method employed two conditions. The threshold value was set at the lower limit of the generated flow accumulation using hydrological modeling in GIS to identify the potential water flow path\(^{39}\), and the threshold value was set equal to one percent of the upper limit of the generated flow accumulation using Terrain Processing in ArcHydro. This method was used to evaluate the urban spatial characteristics of traditional cities such as a Japanese castle town based on watershed analysis\(^{43}\).

In the fourth method, the smallest weighted support area threshold was identified through a defined channel network where the mean stream drop in the first order stream is not statistically different from the mean stream drop in the higher order stream. It was used to define the threshold through an advanced mapping of the flow network from DEMs\(^{47}\).

In the fifth method, the threshold was defined through two modified algorithms: the headwater-tracing method and the fitness index\(^{31}\).

From the five aforementioned methods, it can be confirmed that the definition of thresholds is variable and differs between planners.

b) Urban watersheds

In urban watersheds, the stream network cannot be automatically delineated in its urban terrain since the flow no longer follows its natural path. In urban watersheds the drainage flow path tends to encounter hindrances to flow such as street gutters, which is a result of urban development in the built environment, including buildings, roads, highways, subways, railways, and sewage lines. Basically, the surface drainage system flows through gutters and channels into storm water inlets, which are installed for the purpose of draining the excess runoff from impervious surfaces, namely artificial structures such as paved streets, roofs, sidewalks, and parking lots. The subsurface drainage network of storm sewer pipes, into which the surface water is directed by storm water inlets, is the other drainage network considered in urban watersheds.

For urban watershed planning, the computer-based area-based terrain representation TIN was used with GIS-ARC/INFO to model the storm water flow. It serves as a valuable tool for urban planning and design, especially as it can be used to predict the impact of proposed land use changes and to evaluate land use management strategies. In addition, a tool was developed for further incorporating the GIS spatial analysis into the hydrologic analysis of an urban watershed\(^{22}\). The change of land use in a single lot with a city block corresponding to the nearest storm drain was defined through urban storm watershed modeling\(^{33}\).

These methods can be effective for developing countries, in which the urban flooding associated with surface and subsurface drainage systems is the main urban watershed management issue. Though the applied data are different in scales and resolution, this shortcoming can be minimized through selection of the data sources with minimal scale differences, with the exception of soil maps. However, this method still has some limitations, including digital format availability\(^{33}\). These limitations are even more significant in developing countries, where digital data are less available.

5. RESEARCH TRENDS IN FACTORS CONSIDERED IN WATERSHED-BASED LAND USE ANALYSIS

In this section, 36 of the 55 papers are analyzed and categorized according to each factor in their analysis, while the other 19 papers employ mainly basic tools.

Certain papers have two or more purposes defined in a single paper, while some papers have only one purpose associated with the factors. The factors are counted as the basis of all purposes in each target academic paper.

Two main issues are discussed: (1) research trends in factors considered in watershed-based land use analysis, and (2) the relationship of these factors as shown in Table 2.

In this paper, two scales were used in the context of watershed-based land use analysis. ‘Local scale’ refers to city, regency, district, town, township, ward and village scales, while ‘regional scale’ refers to province or county scale. These scales depend on the territorial division of each country.
Table 2 Relationship of factors, characteristics of study region, scale and area in watershed-based land use analysis.

(*) Size of the study area is watershed or catchment area/** is drainage area/(**) is watershed area corresponding to administrative area

| Factors | Purposes | Research trends in factors considered in watershed-based land use analysis |
|---------|----------|--------------------------------------------------|
|         |          | Methodologies | Ref. N° | Study region and size of study area (km²) | Scale |
|         |          |               |         |                                             |       |
| **Land use policies** | Identification of the effectiveness of green space and local land use policies at a watershed scale | • Quantification of percolation based on land use policies, green conservation policy scenarios | 40) | Asia | 435*** | City |
|         |          | • Quantification of forest and farmland ratio | 6); 41) | 784**; 21* | City and Ward |
|         |          | • Quantification of percolation based on first and second stream order by Horton Strahler | 46) | 41.3* | Ward |
|         | Studies of current policies on watershed conservation | • Based on land use policies documents and interviewing | 3); 42) | North America and Oceania | 2776**; 365** | Regional |
|         | Analysis of the influence of land use policies on land use structure | • Considering slope degree as the most important factor | 48) | Asia | 3.9* | Village |
| **Water Quality** | Exploring the relationships between water quality and land use | • Biology, water chemistry and habitat were used to demonstrate the relationship between the quality of the receiving river and land use | 51) | North America | 4550** | Regional |
|         |          | • Electrolytic conductivity as indicator | 34) |     | 9700** | Regional |
|         |          | • The parameters of the water quality such as total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) | 10) |     | 2840.7** | Regional |
|         |          | • Water Quality Index as indicator | 12) | Asia | 50* | District |
|         | Assessment of the impact of land use and land cover changes (LUCCs) on the surface water quality | • Water quality parameters (WQPs) such as pH, TAN, BOD5, FCs, TCs, EC, NO⁻³, and NO⁻² as indicators | 52) | Europe | 5063.9* | Regional |
| **Surface runoff** | Identifying, estimating, analyzing, quantifying, and simulating the impact of land use change | • Estimation of the increase of annual average runoff from watershed using the L-THIA model | 2) | North America | 70.5* | Regional |
|         |          | • Estimation of surface runoff using the combination between the LTM and L-THIA model | 27) |     | 7032* | Regional |
|         |          | • Surface runoff simulation defined through the combination of the SCS model and storm water management model | 29) | North America and Europe | 1963*; 4007* | Regional and District |
|         |          | • Qualification of the impact of land use change on surface runoff with the aid of the SWAT hydrological model | 23); 53) |     | 0.26*; 82*; 316* | Regional and District |
|         |          | • Calculating surface runoff from satellite image information | 11) | North America | 373* | Town |
| Activity                                                                 | Region | Method                                                                                           | Location 1 | Location 2 | Significance |
|-------------------------------------------------------------------------|--------|--------------------------------------------------------------------------------------------------|------------|------------|--------------|
| Defining the runoff generation mechanism by three methods               |        | • Defining the runoff generation by using WASIM-ETH                                              | Europe     | 100' - 500' | Regional     |
| Defining the characteristics of flood-prone areas                       |        | • Raster format map with derived hydrological products and field investigation                  | Africa     | 1152***    | Regional     |
|                                                                          |        | • Identification of potential water paths                                                        | Asia       | 21.54***   | Town         |
| Analyzing the effectiveness of planning approaches                       |        | • Study of two drainage design methods under different scenarios                                 | South America | 726***   | Regional     |
|                                                                          |        | • Analyzing Ian McHarg's ecological planning approach                                            | North America | 94.2**  | Township     |
| Land suitability analysis for establishing the most appropriate desirable direction for future land use development |        | • Criteria were defined through an ecological inventory in terms of primary, secondary, and unsuitable suitability | North America | 62.160* | Regional     |
|                                                                          |        | • Criteria considered slope degree using the relative land use suitability index                  | Asia       | 3.9*       | Village      |
| Land suitability and allocation analysis                                  |        | • Criteria including the maximization of housing and employment capacity, capability between land use and the minimization of NPS pollution were set as objectives in association with the global spatial trend | Asia       | 180.75*    | District     |
|                                                                          |        | • Integration of GIS and an optimization model to define the future land use allocation based on the inexact-fuzzy multi-objectives linear programming (IFMOP) model | Asia       | 2565*      | Regional     |
| Define the best spatial location, considering economic, natural resource, and social factors |        | • Land suitability evaluation focused on soil types, slope gradient, landform, and slope aspects for rain-fed agriculture. A comparison of land suitability, current land use, and the potential land use scenarios based on surveys on biophysical, socio-economic parameters in the catchment and plans by authorities, was used for further evaluation of their effects on soil erosion, economic feasibility, and social acceptance | Asia       | 3.5*       | Village      |
|                                                                          |        | • With the aid of GIS Multi-criteria analysis in modeling future land use planning for resource planning and management based on biophysical parameters | Africa     | 12,225*    | Regional     |
|                                                                          |        | • Estimation of soil erosion and economic feasibility analysis based on the cost-benefit ratio of land use types in the watershed | Asia       | 583.3*     | Regency      |
(1) Trends in factors considered in watershed-based land use analysis

The research trends in watershed-based land use analysis were analyzed and categorized into six factors: land use policies, water quality, surface runoff, flooding control, land suitability and allocation analysis, and landscape structure.

a) Land use policies

Many methods contribute to the study of watershed-based land use analysis in terms of land use policies. Three main methods focusing on the influences, impacts, and consequences of land use practices on watershed-based land use policies were identified.

First, in order to identify the effectiveness of green space and local land use policies at a watershed scale, the quantity of percolation was quantified based on the land use policy and greenery conservation policy scenarios. The effectiveness of the current conservation of green space was revealed. Quantifying the forest and farmland ratio was also used for environmental conservation and disaster prevention. The effectiveness of using the watershed as a planning unit to reflect finer level planning in terms of natural conditions and social background was defined, and the environment of small watersheds was evaluated. Percolation, with the index of the water cycle focusing on the first and second stream order by Horton-Strahler, was quantified. Transformation of the green space environment on both scales made it possible to consider the restoration of the policy.

Second, in studies of current policies on watershed conservation, studies of land use policy documents were conducted, and policy-makers were interviewed. Negligible numbers of land use planning measures for protecting forest and open space through the watershed were found. In addition, state officers and local community organizations were interviewed, and delivers urgent issues were carried out.

Third, the influence of land use policies on land use structure was analyzed using slope degree as the defining factor. The new land use system was found to be better than the previous one.

b) Water quality

Generally, the study of stream quality and function depends on five variables: climate, geology, soil, land use, and vegetation. Land use is considered to have direct control of and impact on watershed health. These impacts are dominated by contaminants released into the natural environment, which are normally classed as point source and non-point source pollution. Water pollution affects two separate resources: surface water and groundwater. However, in the study of watershed-based land use analysis, surface water pollution is the primary focus among researchers. This pollution is mainly due to the gradual progression of the urbanization process, in terms of discharge from wastewater treatment plants (WWTP), excess fertilizers from agricultural lands, causing a number of ecological effects and adverse health due to an overabundance of nutrients including nitrogen and phosphorus in the water, residential areas, and toxic chemicals from urban runoff.

Many researchers have studied and discussed water quality as one of the factors considered in watershed-based land use analysis. This research can be classified as having two main purposes, each with different corresponding methodologies.

The first purpose is to explore the relationship between water quality and land use. In this context, biology, water chemistry, and habitat were used to demonstrate the relationship between the quality of the receiving river and land use, which showed that increasing population pressures have resulted in increasing loads of nutrients and other pollutants in
the watershed\textsuperscript{51}). Electrolytic conductivity, a general indicator for water quality, is more appropriately used to diagnose the impacts from point pollution sources rather than non-point pollution sources, in order to define the relationship between water quality and land use\textsuperscript{34}. Parameters measuring water quality such as total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) revealed that change in land use types have led to a tendency towards moderate decline in water quality\textsuperscript{40}. The water quality index (WQI) demonstrates that with proper land use planning, water quality can be protected and economic goals can be achieved\textsuperscript{12}.

The second purpose is to make an assessment of the impact of land use and land cover changes (LUCCs) on the surface water quality. Water quality parameters (WQPs) such as pH, total ammoniacal nitrogen (TAN), 5-day biochemical oxygen demand (BOD\textsubscript{5}), fecal coliforms (FCs), total coliforms (TCs), electric conductivity in field (20°C) (EC), total nitrate (NO\textsubscript{3}\textsuperscript{−}), and total nitrite (NO\textsubscript{2}\textsuperscript{−}) were used as indicators. These showed that higher water quality protection can be achieved with greater forest occupation in water reservoirs\textsuperscript{52}).

c) Surface runoff

In general terms, surface runoff is defined as the flow of water occurring when excess storm water is generated during precipitation and snowmelt. It can infiltrate, evaporate, and its runoff can end up in nearby water bodies such as streams, rivers, lakes, and other surface water sources. Moreover, it occurs when there is heavy rain whose flow amount is beyond the absorption capacity of the soil. The increase in the size and number of impervious areas, which is a direct result of land use change and urban development, increases surface runoff. Surface runoff can cause not only water erosion and pollution, but is also the primary cause of urban flooding.

Being aware of and responding to those negative outcomes, many studies have carried out watershed-based land use analysis using surface runoff as a factor. Two main purposes and their corresponding methods were identified in this category of the target academic papers. Surface runoff was used as an indicator in 7 of the 36 target academic papers.

The first purpose is identifying, estimating, analyzing, quantifying, and simulating the impact of land use change on surface runoff. In this context, a long-term hydrological impact assessment, the L-THIA model, was developed for estimating the increase in annual average runoff from the watershed due to land use change. Owing to the intensified pressure on the natural environment due to the increase in impervious areas in the urban environment, the traditional short-term local-scale surface hydrological models focusing on estimating peak discharges and high-magnitude NPS pollution are not sufficient. An increase in annual average runoff volume and metals but decrease in nitrogen and phosphorus load were estimated in terms of increasing urbanization\textsuperscript{3}. Estimation of surface runoff for land use in different periods was defined using a combination of the LTM and L-THIA models. Essential information about future urbanization and the possibility of environmental impacts can be generated; this could be a potential research direction for the future\textsuperscript{27}. Simulation of surface runoff before and after urbanization was defined using a combination of the soil conservation service (SCS) and the storm water management models. A risk of increased flood discharge and decreased quality of aquatic systems was identified\textsuperscript{29}). Surface runoff from satellite image information was also calculated using three methods existing in numerous literatures, namely the SCS, Arthur’s, and Peak surface runoff models. Increased inefficiency in the use of land was also identified as a factor that increases surface runoff\textsuperscript{41}). Moreover, quantification of the impact of land use changes on surface runoff can be conducted with the aid of the SWAT hydrological model, a river basin scale model developed to estimate the impact of land management practices in large and complex watersheds with varying soil types, land use, and management purposes over a long period of time. Surface runoff was identified as the factor most susceptible to land use change in both artificial and natural catchments\textsuperscript{23}). Decreased forest cover led to an increase in surface runoff in the studied watershed\textsuperscript{33}.

The second purpose is to define the runoff generation mechanisms, including infiltration excess overland flow, saturation excess, subsurface storm flow, and quick groundwater outflow, which are likely to be affected by land use change and its influence on storm runoff generation. This study used an extension of the hydrological model, WASIM-ETH, including most of the processes relevant to runoff generation, by considering the spatial distribution of catchment characteristics and spatial temporal dynamics of climate variables, and improving the representation of the influence of land cover and the unsaturation zone on the infiltration process. High dependency on rainfall event characteristics and their spatial scale were identified\textsuperscript{25}).

d) Flooding control

Flood control is becoming one of the major questions in urban planning as well as land use planning. The urbanization process lowers the infiltration rate by substituting impervious cover for natural vegetation, and increases in discharge rate are the direct result of high water velocity. These lead to increased
vulnerability to urban flooding; moreover, these problems are even worse for developing countries since industrialization has concentrated the urbanization process in the past half century. Considering these problems, flood control as a factor in watershed-based planning and land use analysis was categorized with two main purposes.

The first purpose is to define the characteristics of flood prone areas. These were defined through raster format maps with derived hydrological products and field investigation. Flood-prone areas were identified. From the viewpoint of geography and urban disaster prevention, flood-prone areas can be used as hazard maps defined through the identification of potential water paths.

The second purpose is to define the effectiveness of planning approaches. Two drainage system design methods were analyzed: traditional channelization intervention or end of pipe solutions, and the distributed storm water management approach, based on sustainable urban drainage systems (SUDS). The objectives of this is to minimize the quality and quantity problems related to urban development’s effect on the natural environment, and maximize amenities and biodiversity opportunities under different scenarios, considering distinct future urban development possibilities. The traditional approach distributes floods downstream at any time, while the distributed measures over the basin showed a high possibility of adaptation to the future urban pattern. Ian McHarg’s ecological planning approach based on hydrological properties related with land use change, storm water, runoff and discharge was evaluated for its effectiveness for flooding control, and the best solution among the development approaches compared in the study was identified.

e) Land suitability and allocation analysis

Among the target academic papers, two types of analysis were identified considering the influence and impact of land use practices on the natural environment and their related consequences on a watershed scale.

The first type is land suitability analysis, an approach establishing the most appropriate desirable direction for future land use development. In order to identify the most appropriate site, the suitability of various land uses for exploring the growth direction was identified. Criteria for four different types of land use, namely low-density housing, commercial development, industrial development, and recreation were defined using an ecological inventory of the Gila river watershed in terms of primary suitability, secondary suitability and unsuitability for certain land uses. This method can be applied to other rural areas of the American West. Slope degree was considered to be the main factor in the suitability analysis, in particular, for the area dominated by soil erosion by using the relative land use suitability index (R), which was then used to define the suitability of the land use structure. It was clarified that the current land use structure was suitable.

The second type is land allocation analysis, which is conducted to integrate land use planning with effective environmental management, considering economic and social conditions. Land allocation analysis has two general objectives.

The first objective is to define the best spatial location taking consideration of economic, natural resource and social factors. In this sense, the land use optimization plan was defined, focusing on four criteria: the maximization of housing, employment capacity, compatibility between land uses, and the minimization of NPS pollution. It was demonstrated that these models were appropriate for use in areas undergoing urban expansion. Integration of GIS and the optimization model was used to define the future land use allocation based on the inexact-fuzzy multi-objectives linear programming (IFMOP) model, allowing uncertainties including decisions, objectives, and constraints to be communicated in the program and generate solutions. However, this method is for real-time planning; environmental and socio-economic conditions change. An approach to sustainable land use planning satisfying natural eco-environmental conditions, economic conditions, and local farmers’ acceptance and participation, was conducted, where the land suitability evaluation focused on soil types, slope gradient, landform, and slope aspects for rain-fed agriculture. A comparison of land suitability, current land use, and potential land use scenarios based on surveys of biophysical and socio-economic parameters in the catchment and plans by authorities, was used for further evaluation of the effects on soil erosion, economic feasibility and social acceptance. A good choice of land use scenarios with respect to ecological/biological factors was defined. The best allocation of land for future agriculture and forest development was identified with the aid of GIS multi-criteria analysis in modeling future land use for resource planning and management based on biophysical parameters. A realistic soil conservation plan and its implementation in Indonesia was analyzed by conducting an estimation of soil erosion and economic feasibility analysis based on the cost-benefit ratio of land use types in the watershed. It was demonstrated that land use to optimize economic profit/benefit was the preferred option.

The second objective is site prioritization. In this context, the site prioritization was conducted for
In reviewing watershed-based land use analysis, the research trends of basic tools, factors, methodologies, characteristics of study regions, scales, and areas were examined in 55 target academic papers. On the basis of the findings, some conclusions can be made:

First, in recognition of the land use detection method trends, several sources of information including current satellite data and corresponding software were demonstrated to be in use. Furthermore, for high-precision land use detection, the integration of remote sensing (RS) and GIS was proven to be an important technology for temporal analysis and qualification of spatial phenomena, particularly as it allowed for land use analysis with less time and low cost. However, higher spatial resolution satellite data are needed for detecting land use change in detail. Moreover, it has proved to be a useful tool to apply to watershed-based land use analysis with the major methodologies of land use modeling.

Second, terrain analysis based on the digital elevation model has been used widely not only in the fields of hydrology, water resource planning, and other fields, but also in city and regional planning. As the study of the watershed as a planning unit has moved into a new age with the aid of geographical information systems, the definition, application, and the use of a variety of indicators, particularly in rural watersheds, will become even more critical. From the viewpoint of watershed scale planning, the nature of using an application to analyze watersheds is not static. There is much variation among planners because the threshold values, used for stream definition differ. Therefore, close attention should be paid to the process of watershed analysis. With
these concerns as a basis, it is proposed that instead of using constant thresholds, more appropriate and standard methods should be defined in order to bridge the gap between the actual watershed and the watershed delineated in the application. On the other hand, in urban watersheds, where the output information of the modeling is necessary to solve the problem of urban flooding, it is essential for future research to give more attention to the methods, in particular, for the majority of developing countries, where data are lacking and urban flooding is the main issue.

Third, studies have shown that the research trends in factors considered in watershed-based land use analysis and the relationships between these factors, characteristics of study areas, scales, and areas are generally discussed at both the regional and the local scale.

ACKNOWLEDGMENTS: We express our deepest gratitude to the Ministry of Education, Culture, Sports, Science and Technology, Government of Japan for the funding that supported the research for this paper.

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(Received January 19, 2016)