



## **Generating land use changes scenarios for assessing the effects of changes in land use patterns and climate on the quantity and variability of streamflows**

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**Abstract.** Land use pattern change scenarios are required as part of an integrated system in order to examine the effect of land use change together with the climate change on the streamflows, which has been designed as a tool to support an environmentally sustainable development for policymakers.

These land use patterns are constructed in a time-series between 2000 and 2100, with 1990 as the baseline, and are based on four selected policy oriented scenarios (business-as-usual, ecological concern, pro-industrialisation, pro-agriculture). They are created by using a GIS, based on the automata cellular principle.

The implementation of this model in the Upper Citarum river basin, Indonesia, shows the effects of land use change under various policies on the annual yield and seasonal variability flows. The model also shows the importance of land use pattern change in the spatial runoff variation. These results give an opportunity for managing the runoff through land use management as part of an urban development planning, that includes decisions for determining areas that need to be conserved or restored as recharge zones.

*Keywords:* Integrated system, land use change, scenario, streamflows

### **1. Introduction**

Each land use type has its own hydrological characteristics, in particular the evapotranspiration, infiltration and surface runoff coefficient. Therefore, the change in land use can cause the changes in the hydrology such as the seasonal variability and the annual yield of streamflows (Hetherington, 1987; Bruinjeel, 1988; Ferguson and Suckling, 1990; Taniguchi and Bari, 1997; Lørup et al., 1998; etc.). Climate change can also cause the change in the hydrology (Chun-Zen, 1991; Georgiadi, 1991; Mimikou et al., 1991; Murdiyarto, 1996; Arnell, 1997; Orange et al., 1997; Watts, 1997; Wilkie et al., 1999; Arnell and Liu, 2001). These two components, land use and climate, may work together to alter the quantity and variability of the streamflows.

The changes in the seasonal streamflows can have detrimental effects. For examples: lower dry-season flows; increased concentration of pollution because of the reduction of water to dilute; increased risk of floods; increased sedimentation; and increased the need of irrigation network (Muryadi, 1982; Nippon Koei and Nikken Consultants, 1997). Being able to manage the streamflows can reduce the detrimental effects, and in addition, can give many advantages such as: better quality of water; enough debit during the dry-season; reduction of erosion and sedimentation; better quality of ecosystem; and better river aesthetics (Ponce and Lindquist, 1990).

Therefore, an integrated system is required that can examine the impact of land use change and climate change on the streamflows in order to support environmentally sustainable development in a country such as Indonesia. This system should integrate components of land use change, climate change and hydrology into one system. All of these components have to be compatible to each other. Because the climate change is time dependent, therefore the land use change has to be time dependent too.

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For this reason, an integrated system INDOCLIM is developed. This system integrates those three components, and has been specifically designed to examine the effect of land use change and climate change on the streamflows (Santoso and Warrick, 2003; in this volume). The system is user oriented, designed for sensitivity analysis, and designed for small to medium size catchments. The land use component is used to generate land use change patterns based on selected policy-oriented scenarios. The land use patterns are translated into a set of hydrological parameters and, together with the climate variables, are used for calculating the monthly discharge on a cell-by-cell basis. For simplicity reasons, the land use change scenarios are pre-selected and are put off-line in a form of library files. Users will have to choose one scenario from the pre-selected scenarios in order to run the model.

This paper will discuss the method to construct the land use change patterns using a common GIS (Geographical Information System). Before constructing the scenarios, there is a need to analyse in some details the land use change behaviour in the study area. The rates of changes for each land use type and the hierarchy of changes will be discussed. Understanding what cause the land use change will help the scenarios to be constructed with realistic patterns, and when certain policies are introduced, they will be reflected in the generated scenarios.

## 2. Land use change models

Land use is one of three main components of the integrated system INDOCLIM. The land use component is used to generate the land use change patterns based on selected scenarios. The land use change scenarios of the land use change patterns are pre-selected and are put off-line in the form of library files. They are readily accessed when required by users. By putting this component off-line in the form of library files, it is possible to create any scenario of land use change using any land use model providing the model can produce a spatially explicit land use change pattern and in time series. The newly produced results may be used to replace the existing scenarios or can be added into the library files. This creates an advantage by becoming very accommodative that permits users to design the scenarios according to their needs.

There are many land use models already available. These have been reviewed and classified by Lambin (1997). Another review has also been conducted by Irwin and Geoghegan (2001), particularly the spatially explicit ones. The models may range from very simple to complex. Lambin (1997) classified the models based on their methodology and the question that needs to be answered such as when and where the changes may occur in the future, and what drives the changes or why they change (Table 1). The integrated system needs a land use model that can answer where and when the changes take place, i.e. the model can produce spatially explicit and time-dependent land use change patterns. In addition, understanding what cause the changes is necessary in order to determine sets of conditions for changes. The scenarios of changes are produced by altering these conditions.

The dynamic spatial simulation model, such as CLUE (Verburg et al., 1999a) as shown in Table 1, seems to be the most suitable model for constructing land use change scenarios. This dynamic model is designed to predict the land use change and can answer where, when and why the changes take place. However, this model is very data demanding and requires complicated mathematical computation. The land use component of the integrated system is not for predicting the land use change, but for examining the sensitivity of changes on streamflows under various policy-oriented scenarios of changes in land use and climate. Therefore, the use of complicated dynamic spatial simulation model is unfavourable for this purpose.

The required land use model should be able to create land use change patterns easily and not data demanding. Most importantly, it can display patterns of land use change scenarios that can be linked to the hydrological component easily. This leads to the choice of a cellular automata method, which was successfully used by White and Engelen (1993) for predicting future urban development. Hasan (1999) has adopted this method for the development of a scenario generation and evaluation system QUEST (Quite Useful Ecosystem Scenario Tools).

The cellular automata method belongs to a discrete connectionist technique that allows the pattern to evolve in a self-organised manner (White and Engelen, 1993). Based on its nature, this method is spatially explicit. This technique is quite simple. It can be considered as an array of cells in which the state of the discrete cells depends on the state of their neighbouring cells. The change in the state of a cell from one state to another state, i.e. from one land use type to another land use type, is guided by a set of deterministic or probabilistic transition rules. The state of individual cells is then updated based on the state of the neighbouring cells in the previous time period.

This spatially explicit technique can be done on a raster based GIS. To conduct this method, the GIS must have a kind of neighbourhood connectivity function or a user defined filter for convolution operation, which is very common in any standard GIS, e.g. Idrisi (Eastman, 1995) and ILWIS (ITC, 2001). The neighbourhood cells are given certain values according to the degree of their influence on the discrete cell in the centre when this discrete cell is transforming from one state to another state. The assigned values are dependent on their states and distances

**Table 1** Research scenarios on land-cover change and general methodologies (modified after Lambin, 1997).

Example of application	What is already known about the change of process	What one needs to know about the change process	General methodology	Example of tools
1. Climate impact studies	Nothing	When and where	Monitoring techniques	Remote sensing
2. Projection of future surface - atmosphere interactions	When in the past	When in the future	Transition probability models; time-series analysis	Markov chain; logistic function-based models
3. Identification of driving forces	Where and when in the past	Why in the past	Multivariate statistical modelling	Multiple regression models
4. Habitat conservation	Where and when in the past	Where in the future	Empirical spatial models	Spatial statistical (GIS-based) models
5. Future wood resources availability	Where, when and why in the past	When in the future	Ecosystem models	Dynamic simulation models
6. National land-use planning	Where, when and why in the past	When and where in the future	Ecosystem models	Dynamic spatial simulation models
7. Corrective or preventive policy intervention	Where, when and why in the past	Why in the future	Economic models	Von Thünen-like models

from the discrete cell. The resultant value from the neighbourhood cells will determine the new state of the discrete cell.

### 3. Constructing the land use change scenarios

In this study, the cellular automata method is made as simple as possible and the rules of transition, including the values for neighbouring cells, are defined with a simple spatial analysis. It is not intended to exhaustively imitate the method as defined by White and Engelen (1993), because the nature of the cases is very different. White and Engelen (1993) used this method to model urban evolution, which was relatively small in comparison to the size of study area, and there is less variation in land use types than those existing in the study area. Their study permitted an invasion of any urban element into cells with a vacant state, i.e. growth in the total area is permitted, which is not the case in a river basin study where the area is assumed to be constant and there is no expansion of the area beyond the basin boundary. Hence, only a change of proportion is possible.

The procedure to construct land use change scenarios using this cellular automata method involves several steps: defining the hierarchical transition rules that includes the identification of likeliness for a conversion from one state to other states, and understanding the distribution behaviour of land use in the study area; defining the physical-factors such as elevation, slope, and distance from the main road, and land use related weighting parameters; creating weighted map by incorporating the physical-factors and land use related weighting parameters of which the neighbourhood cells are given certain values according to the degree of their influence on the cell in the centre when this central cell is transforming from one state to another state; and processing land use conversion.

The characteristics of land use changes and their distribution are site specific, because many factors that drives the changes, for examples the socio-economics (Turner et al., 1993; Skole and Tucker, 1993) and biophysical factors such as land morphology, soil fertility, etc. (Verburg et al., 1999a; Geist and Lambin, 2001) are different from place to place. This study uses Bandung basin of the Upper Citarum river basin in Indonesia as a case study. This basin is located in west Java, Indonesia, surrounded by volcanic mountains in the north and south with peaks over 2,000m above mean sea level. The centre is relatively flat with an elevation approximately 650m – 675m above mean sea level. The total area is approximately 2,200 km<sup>2</sup>. This area contains several major land use types that are commonly found in Indonesia, such as: forest, paddy-field, dry agricultural land, urban area, and estate crop. These land use types are classified in more detail as described in Table 2. This area is selected as a case study because it has been experiencing a problem of rapid land use change, dominated by increasing residential area as a result of high population with annual rate of growth 3.3% (based on the 1989 to 1997 data from Bureau of Statistics of Bandung Municipality (1991, 1993, 1998) and Bureau of Statistics of Bandung District (1990, 1993, 1998)), and is

particularly suitable for the implementation of the integrated system that examines the impacts of policy-oriented land use change and climate change on the streamflows.

### 3.1 Transitional rules and distribution behaviour of land use

Transitional rules need to be determined based on the behaviour of land use change, including the possible causes of the land use change and the distribution of each land use type. They govern the hierarchy of changes. These rules can be determined through a literature review that includes studies on sociological behaviour of people living in this area (Preston, 1989; Verburg et al., 1999b) and statistical analyses (Karsidi, 1998). When socio-economic data and multi-temporal land use maps are available, comprehensive statistical analyses can be conducted to increase understanding on the behaviour of changes that include: a correlation analysis between the land use variables; socio-economic analysis through simple graphical analysis and correlation analysis; and a regression analysis between the socio-economic variables against the land use variables. It shows that, for examples: the correlation factors between open land and settlement/industry are +0.78 and between grassland and settlement/industry +0.77, suggesting that the open land and grassland is associated with industrial and settlement area; population is well correlated with the number of industries (+0.57), suggesting that the increase in population is also related to the number of industries; the industries are also correlated, even though not strongly, with the number of high school students (+0.49), households (+0.41) and population density (+0.40), which may suggest that the industries to some extent are influenced by demographic factors; a negative correlation between the number of industries and agricultural land may imply that most of the industrial area is converted from agricultural land; and another negative correlation may imply that the settlement area could have been obtained by converting the forest.

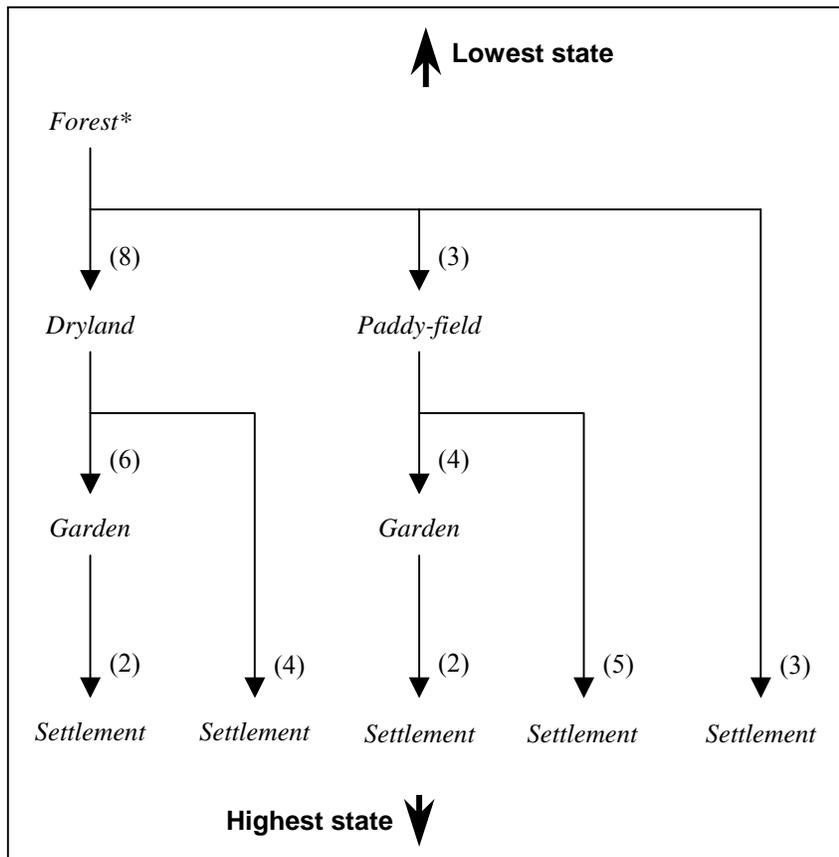
**Table 2** Land use classification of Bandung basin.

Land use class	Description
1. Forest	
1.a Primary forest	Natural forest that contains a mix of tropical forest trees.
1.b Secondary forest	Mainly the re-growth forest containing bush and new trees.
1.c Reforested land	Replanted forest that contains single or limited types of trees such as pine, bamboo, etc.
2. Paddy-field	
2.a Irrigated paddy-field	This paddy-field receives water through irrigation network. It can be identified in the field by the presence of check dams or weirs. Normally farmers can plant paddy three times in a year.
2.b Rainfed paddy-field	This paddy field receives water mainly from rain. It can usually produce a rice crop once or twice in a year, depending on the amount of water normally available, and is followed by a dry season crop (secondary crop).
3. Dry agricultural land	
3.a Dryland ( <i>tegalan</i> )	This is basically dry land cultivated for seasonal crops such as dryland paddy, secondary crops such as maize, cassava, peanuts, soybeans, and sweet potatoes. This land is separate from the house garden and is usually in the upland.
3.b Mixed garden	This type of land is used to produce a wide variety of food crops. In general, the crops are annual or perennial, but sometimes seasonal crops are also found in gardens. Usually, the households plant taro, cassava, pineapple, clove; and fruit trees such as bananas, mangoes, rambutans, coconuts, jackfruit, breadfruit, oranges, papayas, etc. in the gardens. Many geographers distinguish gardens from dry land ( <i>tegalan</i> ) by associating the location of this land with its environment, of which most of gardens are in villages or kampongs and among houses.
3.c Vegetable garden	This is very similar to dryland in its characteristics. The difference is mainly in the types of crops that grow on this dry agricultural land. The crops consist mainly of vegetables such as cabbages, lettuces, carrots, onions, tomatoes, chillies, long beans.
4. Estate crops	Estate crops are agricultural commodities, which are usually exported. Many

4.1	Tea estate	estates are owned by the government but some estates are privately owned. There are two crops in Bandung basin: tea and cinchona.
4.2	Cinchona	
5.	Urban area	An area is classified urbanised if human activity, in particular economic activity, is considerably high, or the density of houses is relatively high. Hence, an area of land with some isolated houses is not considered an urban area. This area can be classified further into settlement area and industrial area.
5.a	Settlement	
5.b	Industrial area	

In summary, the information of the likely transition from one land use type to another type is as follows: 1) the decrease in agricultural land is affected by the change in the number of industries; 2) the decrease in forest is affected by the percentage change in the number of school students and the growth rate of the school students; 3) open land and grassland to some extent are part of the settlement/industrial area; 4) there is no consistent rule in the order of the land use conversion hierarchy, i.e. it is possible that agricultural land is converted into settlement/industrial areas, or forest into settlement/ industrial areas.

Based on the literature review and statistical analyses, a schematic hierarchy of land use transition in the study area can be drawn (Fig. 1). This Fig. illustrates a simple and general transition-rule of main land use types (forest, paddy-field, dry agricultural land, urban area, and estate crop). In the actual computation, this land use transition is more complicated allowing more detailed land use types such as primary forest, secondary forest, and transition from dryland (*tegalan*) to non-irrigated paddy-field or irrigated paddy-field, conversion of mixed-garden to vegetable garden and vice-versa. The conversion of land does not have to be in a sequential order, but it has to follow the transition rule from a low state in the hierarchy to a higher state. Forest (secondary forest) may change to dryland (*tegalan*), paddy-field or settlement. The dryland may change to garden (both vegetable garden and mixed-garden), or settlement, and the garden may change to settlement. Paddy-field may also change to garden or settlement.



\*Forest in this case is the secondary type.

Fig. 1 The transition hierarchy of land use change in Bandung basin.

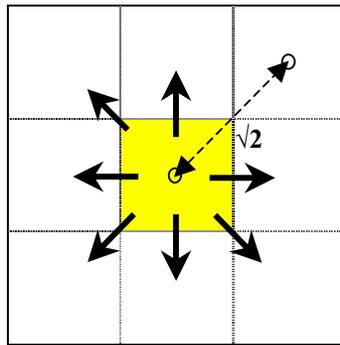
The Fig.s beside the arrow-lines (Fig. 1) indicate relative likelihood of changes from one state to another state on a scale of 0 to 10 for very unlikely to very likely. These values are arbitrarily assigned, based on expert knowledge and field observations, supported by the information deduced from the literature review and statistical analyses. They are required for predetermining weighting factors. The change from dryland to garden, for example, is more likely than the change from dryland to settlement, because there is a tendency for the society to conserve agricultural land (Verburg et al., 1999b). The conversion of paddy-field to settlement is much more likely than the conversion of paddy-field to garden. This has been found to be the case in the field, where new settlement areas are usually taken from paddy-field areas while the conversion of gardens to settlement area is less favoured.

As mentioned earlier, land use distribution is controlled by the physical factors such as elevation, slope, distance from the main road, and distance from the river. In this study, the distribution of each land use types with respect to those factors are analysed using simple distribution graphics. The priority growth areas for urban are in areas with elevation of less than 1000m and with slopes of less than 10%; vegetable gardens is preferable to expand on land with an elevation between 1000m and 1500m and with a slope of less than 20%, and this type of garden is the priority for growth in these conditions, rather than dryland (tegalan) and mixed-gardens; there are no restricting conditions in terms of slope and elevation for the expansion of dryland (tegalan) and mixed-gardens; there is no restricting condition in terms of slope and elevation for the expansion of paddy and forest, but it is very likely that their sizes will reduce following the expansion of the other land use types (urban and dry-agricultural land); about 60% of urban areas are located within a distance of less than 500 m and about 90% are within a distance of 1500 m, which imply that urban areas are preferred to be located in places that are easily accessible and the growth of urban areas is likely to take place near the main road if space is available; the dry-agricultural land is distributed randomly with respect to the distance from the main road, except for the vegetable gardens that are preferred to be located at a distance of less than 1300m from the main road; most of forest is located a long distance of more than 2600 m from the main road; and there is no specific patterns of land use distribution with respect to the distant from the river.

### 3.2 Creating weighted map

The whole process for constructing land use change scenarios has been conducted on a GIS package named ILWIS 3.0 (Integrated Land and Water Information System - Version 3.0) (ITC, 2001). A user specified filter is used to construct the new land use patterns. The calculation works only on a raster format digitised map, of which each individual pixel (cell) contains a numerical value. ILWIS has a predetermined neighbourhood function, which is a filter function that only works on a 3x3 cell (8 connected neighbouring cells, see Fig. 2). These 8 connected cells fall within a distance of up to  $\sqrt{2}$  units. If the pixel size is 100m, then the real distance is up to 141.4m. In reality, the influential distance for land use transition is up to 500m or more. Within such a distance, a variation in the degree of influence is likely to occur depending on the state of the cell and the distance from the central cell. To extend the influential distance up to 500m, the designed filter has to be 11x11 for the pixel size = 100m (Fig. 3). All cells that fall within a radius of 500m (or up to a distance of zone 13) are given a value of 1, and the rest are given a value of 0. If the influential distance is up to 400m, the corresponding distance zone is 9. All the cells within a distance zone of 9 or less are given a value of 1, and the rest are given a value of 0, and so on. Thus, the size of the distance-influence filter is dependent on the maximum influential distance and the pixel size.

The values of 1 and 0 in the filter (Fig. 3) are called the filter coefficient. For many filters, the values are not always 1 or 0. When this filter is assigned to a raster-based map, a convolution operation is performed. It operates by multiplying each pixel value of the map with the corresponding coefficient in the filter. All the values gained are summed and the resulting value replaces the original value of the central pixel.



**Fig. 2** A 3x3 filter with 8-connected neighbouring cells around the central cell.

539	447	361	283	224	200	1	1	1	1	1	0
583	500	424	361	316	300	1	1	1	1	1	0
640	566	500	447	412	400	1	1	1	1	0	0
707	640	583	539	510	500	1	0	0	0	0	0
Real distance in meters*						Designed filter**					

**Note:** \* The pixel size is assumed to be 100 m.  
 \*\* The influential distance is assumed up to 500 m (distance zone 13).  
 The shaded cells are assumed to be the central cell.

**Fig. 3** Creating a distance-influence filter for a known distance/radius.

Weighted maps need to be constructed first before the convolution process is conducted. The following data need to be prepared as inputs to the GIS:

- A digitised land use map and other necessary maps such as a slope map, digital elevation map (DEM), main road map, etc.;
- Weighting factors to be defined from the likelihood of transition from one state to another state (which is already given in the hierarchical transition rules), and the likelihood of one cell influencing the conversion of a discrete cell from one state to another state, which depends on its current state and the distance from the discrete cell;
- Resisting boundary, which is a collection of physical factors that may resist or refrain the land use conversion;
- Other factors that may influence the distribution of the land use, such as distance from main roads.

All the thematic digital maps can be prepared or derived come from a topographic map (GTL, 1992); a land use map (Suhendar, 1989); a geological map (Dam et al., 1993) of Bandung Basin area using this GIS. The land use map dated 1989 is used as the basis for generating future scenarios. Each land use unit has to be separated from each other, which will be used to generate distance maps for an individual land use unit. The elevation map is made by interpolating the contour from the topographic map, which is used to produce a slope map. The main road distance map is made by a applying a distant calculation function to the main road map. All of the prepared maps are in a raster format, in which they all must have the same geo-reference system and the same cell size.

There are two kinds of weighting parameters. The first kind is land-use-related weighting parameters. These are the weighting parameters that influence the transition of a cell from one state (land use) to another state, because of the state and the distance of a neighbouring cell from the central cell. The other one is physical-factor-related weighting parameters. These are weighting parameters that usually discourage the transition of a cell from one state to another state because of the presence of the physical factors.

The land-use-related weighting parameters are identified in three steps. The first step involves assigning estimated values of the degree of influence of the cells in the neighbourhood for a particular transitional process from one land use type to another type. The values are estimated based on expert knowledge. This process is very subjective, and

**Table 3** Weighting parameters for transition from state *i* to *j*.

		Distance zone, <i>d</i>									
State, <i>k</i>		1	2	3	4	5	6	7	8	9	10
		100	141	200	224	283	300	316	361	400	412
		Distance in meters (cell size = 100m)									
<b>I</b>	<i>From: Primary forest</i>	<i>to: Urban</i>									
	<i>Primary forest</i>	-0.3	-0.3	0	0	0	0	0	0	0	0
	<i>Secondary forest</i>	0	0	0	0	0	0	0	0	0	0
	<i>Reforested</i>	0	0	0	0	0	0	0	0	0	0
	<i>Irrigated paddy</i>	0	0	0	0	0	0	0	0	0	0
	<i>Rainfed paddy</i>	0	0	0	0	0	0	0	0	0	0
	<i>Vegetable garden</i>	0	0	0	0	0	0	0	0	0	0
	<i>Mixed garden</i>	0	0	0	0	0	0	0	0	0	0
	<i>Tegalan (Dryland)</i>	0	0	0	0	0	0	0	0	0	0
	<i>Urban</i>	0.75	0.75	0	0	0	0	0	0	0	0
<b>III</b>	<i>From: Irrigated paddy</i>	<i>to: Urban</i>									
	<i>Primary forest</i>	0	0	0	0	0	0	0	0	0	0
	<i>Secondary forest</i>	0	0	0	0	0	0	0	0	0	0
	<i>Reforested</i>	0	0	0	0	0	0	0	0	0	0
	<i>Irrigated paddy</i>	0	0	0	0	0	0	0	0	0	0
	<i>Rainfed paddy</i>	0	0	0	0	0	0	0	0	0	0
	<i>Vegetable garden</i>	0	0	0	0	0	0	0	0	0	0
	<i>Mixed garden</i>	0	0	0	0	0	0	0	0	0	0
	<i>Tegalan (Dryland)</i>	0.5	0.5	0.5	0.5	0	0	0	0	0	0
	<i>Urban</i>	5	5	3	3	1	1	1	1	0	0

largely relies on the knowledge gained from field observation and the study of transitional-likelihood in the hierarchy. The next step is a readjustment of the values involving a process of assigning the maximum values according to the value of conversion likelihood (see Fig. 1), while the rest are readjusted by simple proportion. The last step is fine adjustment of the weighting parameters which can only be conducted by examining some results of processes that have been computed. This will check whether the process of land use conversion behaves correctly.

Examples of the land use related weighting parameters are listed in Table 3. (Only two blocks are shown here for the purpose of explanation.) Each block of rows assigned with a Roman numeral, contains the parameters for calculating one potential transition. Each row within the block contains weighting parameters applied to a land use unit in distance zone 1 to 10 (100 m to 412 m). For example: block I - for a conversion from primary forest to urban, if the land use type of a cell is primary forest (first row in block I) and is located either at distance zone 1 or 2, the weighting parameter is -0.3. It means that the presence of primary forest at a short distance of less than 200 m is likely to discourage the conversion of a cell from primary forest to urban. The discouraging influence is indicated with a negative sign. However, the presence of urban area at this distance (last row in the same block) is likely to attract the conversion of the primary forest to urban (weighting parameters = +0.75). Block III shows that the transformation of a cell from irrigated paddy to urban is largely encouraged by the presence of an urban area in its neighbourhood (last row in block III), but its influence decreases gradually with distance (weighting parameter = 5 at the shortest distance and = 1 at the distance zone 8).

The physical-factor-related weighting parameters are the parameters that control the distribution of the changes in land use. The weighting parameters from the physical factors that influence the distribution of the land use changes are listed in Table 4. These numerical values of the weighting factors are estimated based on the previous discussion and are readjusted after examining the results of some computational processes. If there are no physical factors that restrict the land use conversion, the value is 0.

**Table 4** Weighting factors with respect to elevation, slopes and distance to the main road.

Land use type	Weighting Factors (WF)					
	Elevation (m)	WF	Slope (%)	WF	Distance from the main road (m)	WF
1. Urban	< 745	Na	< 5	na	< 100	+0.16
	745 - 845	-0.4	5 - 10	-0.6	100 - 200	na
	> 845	-0.6	> 10	-0.8	200 - 400	-0.1
					400 - 1,400	-0.2
					> 1,400	-0.3
2. Dry agricultural land	2.a Vegetable garden					
	< 745	-0.4	< 5	-0.3	< 2,200	na
	745 - 1,045	-0.3	5 - 10	na	> 2,200	-0.1
	1,045 - 1,145	-0.2	10 - 15	-0.2		
	1,145 - 1,245	Na	15 - 30	-0.4		
	1,245 - 1,345	-0.1	> 30	-0.5		
	1,345 - 1,445	-0.2				
	1,445 - 1,545	-0.3				
	> 1,545	-0.4				
	2.b Mixed-garden					
	< 745	-0.2	< 5	-0.1		na
	745 - 1,045	Na	5 - 10	na		
	1,045 - 1,245	-0.2	10 - 15	-0.1		
> 1,245	-0.3	15 - 20	-0.2			
		> 20	-0.3			
2.c Dryland ( <i>tegalan</i> )						
< 1,045	Na	< 10	na		na	
1,045 - 1,245	-0.1	10 - 15	-0.1			
> 1,245	-0.2	13 - 35	-0.2			
		> 35	-0.3			
3. Paddy	3.a Irrigated paddy					
	< 745	Na	< 5	na	< 3,400	na
	745 - 845	-0.3	5 - 10	-0.4	> 3,400	-0.1
	845 - 1,045	-0.4	10 - 15	-0.5		
	> 1,045	-0.5	> 15	-0.6		
	3.b Rainfed paddy					
	< 745	Na	< 5	na		na
	745 - 845	-0.4	5 - 10	-0.5		
	845 - 1,045	-0.5	10 - 20	-0.6		
	> 1,045	-0.6	> 20	-0.7		
4. Forest	4.a Primary					
		Na		na		na
	4.b Secondary					
		Na		na		na
4.c Reforested						
	Na		na		na	

Note: na = not assigned

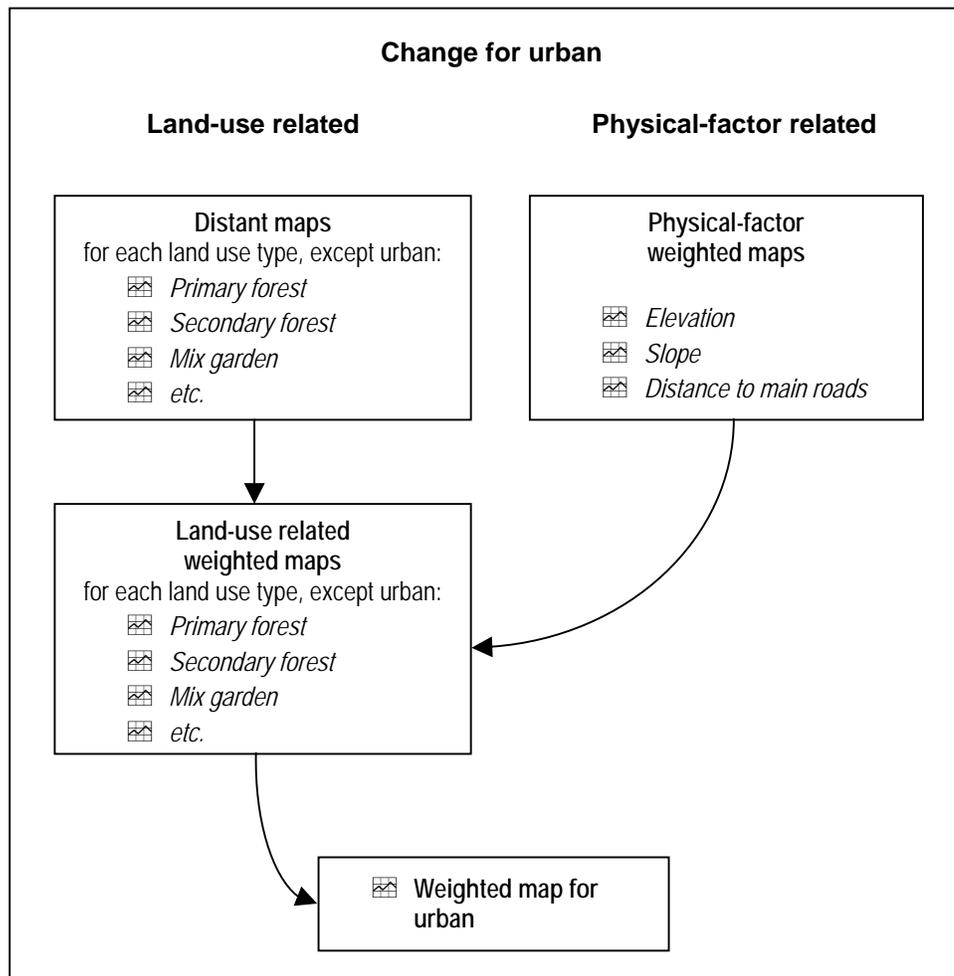
A flood zone is another important natural (or physical) factor that can also influence the distribution of certain land use types, especially the urban area. The flood zone is divided into two sub-zones; the annual flood zone and the flood potential zone. The annual flood zone is the zone where floods occur almost every year and therefore the utilisation of this zone is restricted. The flood potential zone is where floods occur occasionally, for example, every 5 or 10 years. This zone is still susceptible to wet-agriculture but not to settlement and industrial areas. The weighting parameters for the flood zone are given in Table 5.

Creating weighted maps is the final preparation required before applying the filter function. A weighted map is made for individual land use units, for each story-line leading to one scenario. Rigid boundaries that do not allow any land use to cross such as the lake, reforested land, estate crops, are not included in the map and are assumed to remain unchanged during the process. Reforested land is considered a rigid boundary for the scenario of business-as-usual and can be changed to non-rigid for other scenarios.

To create a weighted map for changes of any land use type to a specific land use, for example to create a weighted map for an urban area, the land-use-related weighted maps and the physical-factor-related weighted maps have to be

created first before they are all combined to produce the weighted map for urban change as illustrated in Fig. 4. Creating the land-use-related weighted maps involves two steps. The first one is creating distant maps for each land use type, except for urban area. This process can be done using a distant calculation function available in the GIS. The second step involves creating land-use-related weighted maps with respect to urban area by utilising the distant maps produced in the first step. This step is basically transferring the weighted parameters (Table 3) for each potential transitional process of land use unit state  $i$  to state  $j$  spatially, for example the transition from primary forest (state  $i$ ) to urban (state  $j$ ), in order to produce a weighted map specific for this potential transition. The process requires a map calculation function, which can be described, for example:

If a neighbouring cell at a distance  $< 200$  m is "primary forest", assign the value = -0.3; if a neighbouring cell at a distance  $< 200$  m is urban", assign value = 5; if between 200 m and 283 m, value = 3; if between 283 m and 361 m, value = 1.



**Fig. 4** The procedure to create a weighted map, with an example for changes to urban area.

The first statement above refers to the first row in block I, Table 3, and the second statement refers to the last row in block III. The same procedure is conducted for the potential transition from other land use types to urban, i.e. secondary forest to urban, vegetable garden to urban, etc.

The physical-factor-related weighted maps are created for each restricting factor, i.e. elevation, slope, and distance from the main roads, with respect to urban area. These physical-factor-related weighted maps are created by using a simple slicing method. Some examples are given here: the elevation-related weighted map for urban area is created by assigning any elevation between 745m and 845m with a value = -0.4, and those higher than 845m are assigned

**Table 5** Weighting parameters of land use conversion in a flood zone.

	Land use	Annual flood zone	Potential flood zone
1.	Urban	-4	-1
2.	Dry agricultural land	N/A	N/A
3.	Paddy		
3.a	Irrigated paddy	-0.5	-
3.b	Rainfed paddy	-0.5	-
4.	Forest	N/A	N/A

Note: N/A = Not applicable

with a value = -0.6 (Table 4). The same applies to slope; any slope between 5 and 10% is assigned with a value = -0.6, and those higher than 10% are assigned with a value = -0.8, and so on.

To create a weighted map for this urban area, all the land-use-related weighted maps and physical-factor-related weighted maps are combined by simple summation, i.e. the sum of all land-use-related weighted maps plus the sum of all physical-factor-related weighted maps.

### 3.3 Processing and time-series generation of land use pattern changes

The process of calculation is conducted by applying a filter function to the weighted map. The filter is designed based on the distance zone (see Fig. 3) and is used for performing a convolution operation. After each convolution, the change in the related land use is analysed by generating the statistics from the map. If the new total area of the specified land use reaches the pre-estimated size of coverage area, the process is stopped. If not, the procedure is repeated, starting with the creation of a new weighted map based on the newly generated map until the specified land use reaches the pre-estimated size. The rate of change for each land use type, or at least the land use type at the highest level in the hierarchy and the one that causes major changes, which is the urban area, must be known. The rate of change of the land use generated from the computation should match with the estimated or predetermined rate by fine-tuning the weighting parameters. This is also a kind of a calibration process for the land use change model to ensure that the model behave correctly as expected.

The method used to calculate the land use change is different from the method used by White and Engelen (1993) even though the basic principle is similar. The main reason is to reduce the complexity of the computation. In addition, the circumstances of the two studies are different and the target for output is also different. The main differences are the way the weighting parameters are assigned and the transitional potential calculation. White and Engelen's method does not give zero values in its computation, and possible transitions are calculated simultaneously. The new land use is automatically determined by the highest potential transition value in White and Engelen's method. In contrast, the method used in this study can produce any values, negative and positive. If a cell gains a positive value, it means that a change occurs. If the cell gains a negative value or zero, it means that the change does not occur. This method results in changes mostly along the margin of the related land use, even though in some places a new cluster can emerge in a distant location from the related land use if the conditions are permitting. The growth of land use can be in any direction and magnitude, depending on the preferences set in the weighted map. The transitional calculation from one land use type to another is conducted manually starting with a land use type, which is the highest level in the hierarchy, and then followed by the next highest, and so on. In the case of two land-use types of equal level, the selection is decided by the physical factors that have more influence over changes. This manual method therefore permits more freedom for monitoring and assessing the changes in land use than the automatic method.

By knowing at least the rate of change of the land use at the highest state in the hierarchy, which is the urban area, it is possible to generate a time series of change in the land use pattern. This is done by projecting the growth of the urban area for a specific time (year), and then converting it into the number of processes required from the computer to process the change in land use until the target amount of growth in the urban area for that specific time is met.

However, the rate of urbanisation in this study area has not been well studied and documented. A study in this basin by Karsidi (1998) showed that the increase in the area of settlement and industries was at an average of 7.8% per year for the period 1984-1996. The forest area was reduced by 2.9%, and the agricultural land was reduced by 4.4% every year in the same period. At a national scale, Cobban (1996) estimated the urbanisation rate for the whole

country at 5% per year, and for the island of Java 1.7% per year for the period of 1980-1990, which is much lower than the national Fig.. Another study (Verburg et al., 1999b) estimates that the percentage of the Java's population living in the urban areas increased from 39% in 1994 to 47% in 2000, and 57% in 2010, or the rate of increase for people living in the urban area is on average 3.16% per year from 1994 to 2000, and 1.95% from 2000 to 2010. This rate of urbanisation is different from the rate of increase in settlement and industrial areas. Therefore, the rate of increase in the area of settlement and industries as given by Karsidi (1998) represents the actual change of land use better than the urbanisation rates given by Cobban (1996) or Verburg et al. (1999b). However, it seems that the value given by Karsidi (1998) overestimates the actual increase in the urban area because the likely demand for settlement areas (not including industries), as indicated by the annual growth rate of population (3.3% for 1989-1997 period) and number of households (2.45% for 1989-1997 period), is much less than the rate of increase in the number of settlement and industrial (urban) areas as given by Karsidi (1989). In addition, the influence of industries on the growth of the industrial area is questionable because, based on the statistical data from 1989 – 1997, the number of large and medium size industries is declining. This study, therefore, uses an estimated rate of increase in the urban area of 5% per year for the business-as-usual condition, which is quite modest in comparison to the value given by Karsidi (1998), which is 7.8%, and slightly higher than the estimated current rate of urbanisation for Java and the rate of increasing population in the study area, which are 3.16% (Verburg et al., 1999b) and 3.3% respectively. The rate of growth is assumed to reduce by 4.7% per year, following the reduction in the rate of urbanisation as estimated by Verburg et al. (1999b).

Rates of change in other land use types are not well studied. Collected information shows very different results. Data from Karsidi (1998) suggested that, for the period 1984 to 1996, the forestland reduced by 2.9% per year and the agricultural land reduced by 4.4% per year. A linear extrapolation using these rates shows that all agricultural land and forest in the Bandung basin would vanish by 2015 and 2022 respectively. Collier et al. (1993) [cited in Verburg et al. (1999b)] also foresaw that in the year 2025 all of Java except the most eastern and western parts will be totally urban. However, a land use model for Java by Verburg et al. (1999b) indicates that in 2010, in spite of high absolute changes in the land use, the changes take place dominantly in the lowland areas where there is a decrease in paddy-fields due to an increase in housing area, and estate crops and, in addition, there is also an increase in dry-agricultural land (i.e. agricultural land still exists, and in particular dry-agricultural land is increasing). The changes in highland areas, in particular the forest area, are less pronounced.

For the model in this study, the rate of land use change relies only on the growth rate of the urban area (settlement and industrial area). This is considered the main type of land use that drives land use change because it is controlled directly by demand from society. This model can include the rates of change of one or two other land use types. However, this may cause exhaustive adjustment of the weighting parameters, which may not be necessary for the purpose of the integrated system. Furthermore, as discussed earlier, definite rates of land use change are not yet known.

### 3.4 Scenarios generation

The land use component is part of the integrated system for examining the impact of changes in land use and climate on the streamflows. Scenarios of land use changes are generated in order to reflect the plausible future land use patterns. Each scenario contains a coherent and internally consistent set of parameters, with reasonable descriptions of possible future states. Therefore, a scenario is not a prediction of a future state.

Policy-oriented scenarios are selected with the aim of looking for a wide range of possible patterns for this integrated system. Each scenario contains a defined story-line or some conditions which will determine the future patterns of the land use. The scenarios are: business-as-usual, ecological/environmental concern, pro-industrialisation, and pro-agriculture. The conditions for each scenario is summarised in Table 6 and described in more detail below.

#### *Business-as-usual*

The business-as-usual scenario is based on conditions of the last 10 to 15 years. The rate of change for each land use is kept constant. This business-as-usual scenario is considered as the reference policy. This scenario uses the weighting parameters that have been constructed as discussed in the previous section. The rate of growth for the urban area is 5%.

#### *Ecological/environmental concern*

In this scenario, regulations regarding land use are strictly enforced. They include protected zones as described in the Presidential Decree No. 32/1990 regarding the definitions of protected zones, and regulations regarding the

**Table 6** Conditions for various policy oriented land use change scenarios.

	Policy/condition	Description
1.	Business-as-usual	Applying the same condition and rates of changes as for the last 10 to 15 years. Rate of increase in urban area is 5% per year.
2.	Ecological concern	A condition that prioritises the protection of environment and ecology. With this condition, forest cutting is not permitted. The government regulation regarding the land use in the northern Bandung basin is strictly enforced, and zones around the riverbanks are protected or restored according to the regulation. Rate of increase in urban area is assumed 5% per year.
3.	Pro-industrialisation	A condition that encourages industrialisation, and therefore may encourage rapid urbanisation. Conversion of agricultural land and forest to industrial and settlement areas is permitted. Rate of increase in urban area is assumed 7.5%.
4.	Pro-agriculture	A condition that encourage activities in the agricultural sector. Conversion of forest to agricultural land is permitted. The conversion of agricultural land to urban areas is discouraged and the urbanisation rate is reduced to a low level. Rate of increase in urban area is assumed 2.5%.

recommendation of land use allocation in the North Bandung region (Governor's Decree No. 181.1/SK.1624/Bapp/1982), and No. 413.21/SK.222-Huk/91 regarding the locality criteria and technical standard for spatial land use for Puncak region, which is adopted for the North Bandung region; Ciptakarya, 1996). The North Bandung region has special treatment because this region contributes at least 60% of all groundwater that of the Bandung basin and there is a great concern that those responsible for the development in this region have paid little attention to its ecology. Conversion from one land use type to another type is regulated. In a simple way: wetland agriculture (paddy-field) *may not* convert to any other land use types, dryland (*tegalan*) *may* convert to any other types, and garden (vegetable and mixed-garden) *may not* convert to paddy-field and dryland (*tegalan*).

For generating land use patterns with this scenario, the weighting parameters need to be adjusted to fit the conditions as given by the regulation. All forest in the North Bandung region is classified protected and should not be converted to any other land use types. Therefore, the weighting parameter for forest is given a very heavy negative value in order to forbid this type of land use to convert into another land use type. The paddy-field in the North Bandung region is not allowed to convert to other types, whereas the dryland is allowed to convert to other land use types, etc. Some of the land uses which are actually not supposed to be in their location (e.g. based on the land use map dated in 1989, some paddy-fields, vegetable gardens, and cinchona plantations already occupy the protected forest zone), are left as they are. Other parameters, which are not bounded by the rules will use the same parameters as the parameters for the business-as-usual scenario.

The rate of growth for the urban area is 5%, which is at the same rate as the business-as-usual scenario.

#### *Pro-industrialisation*

By encouraging industrialisation, it is expected that more jobs will be created in this sector and the GRDP will rise quickly. Industrialisation is usually followed by other job opportunities in other sectors such transportation, services, etc. and therefore attracts more people to relocate to the urban area which causes a rapid increase in urbanisation and demand for settlements. Some agricultural land, in particular paddy-fields, are expected to convert into settlement and industrial areas with a higher rate than the rate of the same land use conversion in the business-as-usual scenario.

The weighting parameters for this scenario require an adjustment to allow the expansion of the urban area into agricultural land by increasing the land-use-related weighting parameters. Both the distance-influence zones and the weighting factors are increased to allow rapid conversion of agricultural land to urban area. The parameters that resist the conversion of forest to urban and to agricultural land are also weakened relative to the business-as-usual scenario. However, some degree of conservation to protect the forest is still present.

The rate of growth for the urban area is 7.5%, which is 2.5% higher than the business-as-usual scenario.

#### *Pro-agriculture*

With this pro-agriculture scenario, the agriculture sector is encouraged, for example for self-sufficient food-crops. In this scenario, the loss of agricultural land, in particular the irrigated paddy is designed to be minimal, while the area for agricultural land is allowed to expand onto the forestland. However, this scenario will use the same hierarchical rule as already set for the business-as-usual scenario, where the paddy-field is allowed to convert to mixed-garden and vegetable garden. Therefore, it is expected that with time the relative proportion of the dry-agricultural land will be higher than its current proportion.

The rate of growth for the urban area is 2.5%, which is 2.5% lower than the business-as-usual scenario and significantly lower than the current rate of urbanisation in Java (3.13%).

#### 4. Results

Generated land use pattern composition under various scenarios can be seen in Fig. 5. This Fig. shows a time-series change in sectoral land use. In general, the results show that the urban area reaches the largest area in 2100 under the pro-industrialisation policy, and the lowest under the pro-agriculture policy. The business-as-usual and the ecology concern policies produce almost similar results. For agricultural land, the highest by proportion for the year of 2100 is when the pro-agriculture policy is implemented, in spite of the decrease in the paddy-field. This reflects the trend of change in agricultural land use because of change in diets as suggested by Verburg et al. (1999b). The ecological concern policy produce nearly similar outcomes as the business-as-usual scenario. The main difference is that the ecological concern policy keeps the forest area at the same size as in 1990, whereas the business-as-usual scenario allows conversion of the secondary forest into different land use types. Spatial changes of each scenario

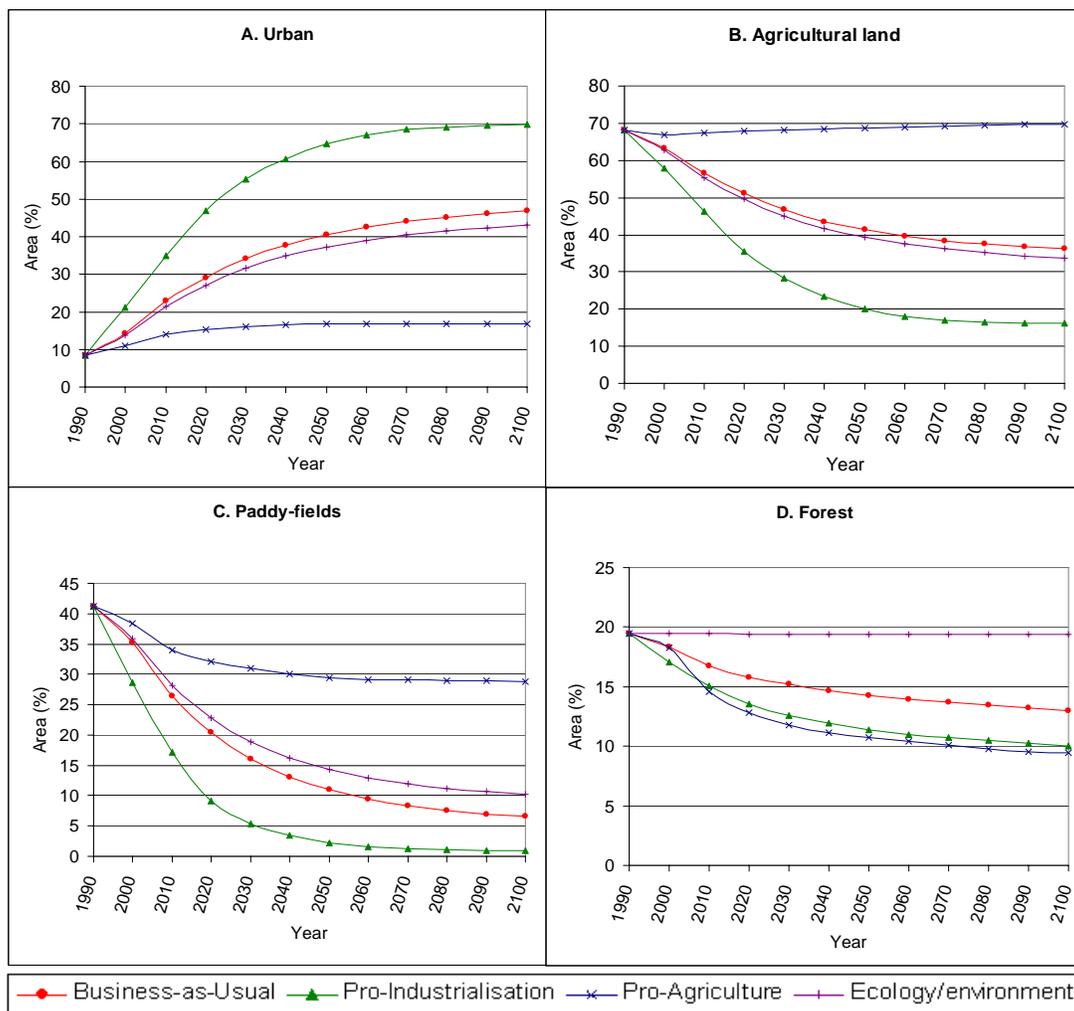


Fig. 5 Sectoral change in land use.

simulation can be described as follows:

- Under the business-as-usual scenario, the urban area will expand first by filling the gap between the existing urban areas and along the east-west main road, and later, it will expand outward to the south (Fig. 6). This is similar to what was predicted by Verburg et al. (1999b) that the outskirts of Bandung city would be one hot spot of change in 2010. The paddy-field will be quickly reduced by the expansion of the urban area, and by 2060 almost all irrigated land is converted to urban area, except in the upland.
- Under the ecological concern scenario (Fig. 7), the forest remains unchanged for the whole process of land use change. The growth of the urban area is similar to the growth under the business-as-usual scenario, except for the North Bandung region (north of the main city) where the urban area is not allowed to expand.
- The pro-industrialisation scenario simulates the rapid increase in the urban area, with the growth in the urban area being 1½ times higher than the reference scenario (Fig. 8). The urban area expands quickly by converting the paddy-field and mixed-garden, and by 2020, nearly all the paddy-field will be converted to urban area. This rate of expansion may decrease quickly as the area becomes saturated. By 2100, about 70% of the basin will be covered by the urban area, leaving some space for forest and vegetable garden.
- The pro-agriculture scenario simulates a low rate of urban growth (Fig. 9). The urban area expands slowly until the year 2040 at about 17% of the total area, and there is no further growth of the urban area beyond this year. The agricultural land expands by converting the forest to dry-agricultural land, mainly to vegetable gardens and mixed-gardens. The paddy-fields are reduced by the growth of the urban area and the conversion of non-irrigated paddy-fields to mixed-gardens.

The integration of the four policy-related land use change scenarios into the integrated system INDOCLIM shows various effects on the streamflows (Fig. 10). The pro-agriculture scenario produces higher annual discharge than the other land use scenarios, which shows an increase of 15% in the mid-century (2050) and nearly 18% in 2100 relative to the current baseline (1990), i.e. the effect of this scenario is greater with time when more land is converted. The ecological concern and pro-industrialisation scenarios show a decrease in the annual discharge whereas the business-as-usual policy shows a small change in the annual discharge. The lowest discharge is obtained under the pro-industrialisation scenario which shows a decrease of 6.8% in 2050 and about 8% in 2080 and 2100.

Seasonal variability is also affected by the land use patterns. This can be easily examined by looking at the relative changes in monthly discharge from various land use scenarios relative to the baseline (Fig. 11). The pro-agriculture scenario produces an increase of seasonal variability in the discharge with the highest increase in July and lowest increases in March and November. The pro-industrialisation scenario produces a large seasonal variation in the discharge, with a large decrease in January to September in comparison with the other scenarios and an increase in November and December. Fig. 11 also shows that the greatest drop in low flow between July and September occurs under the pro-industrialisation scenario whereas an increase in low flow occurs under the pro-agriculture scenario.

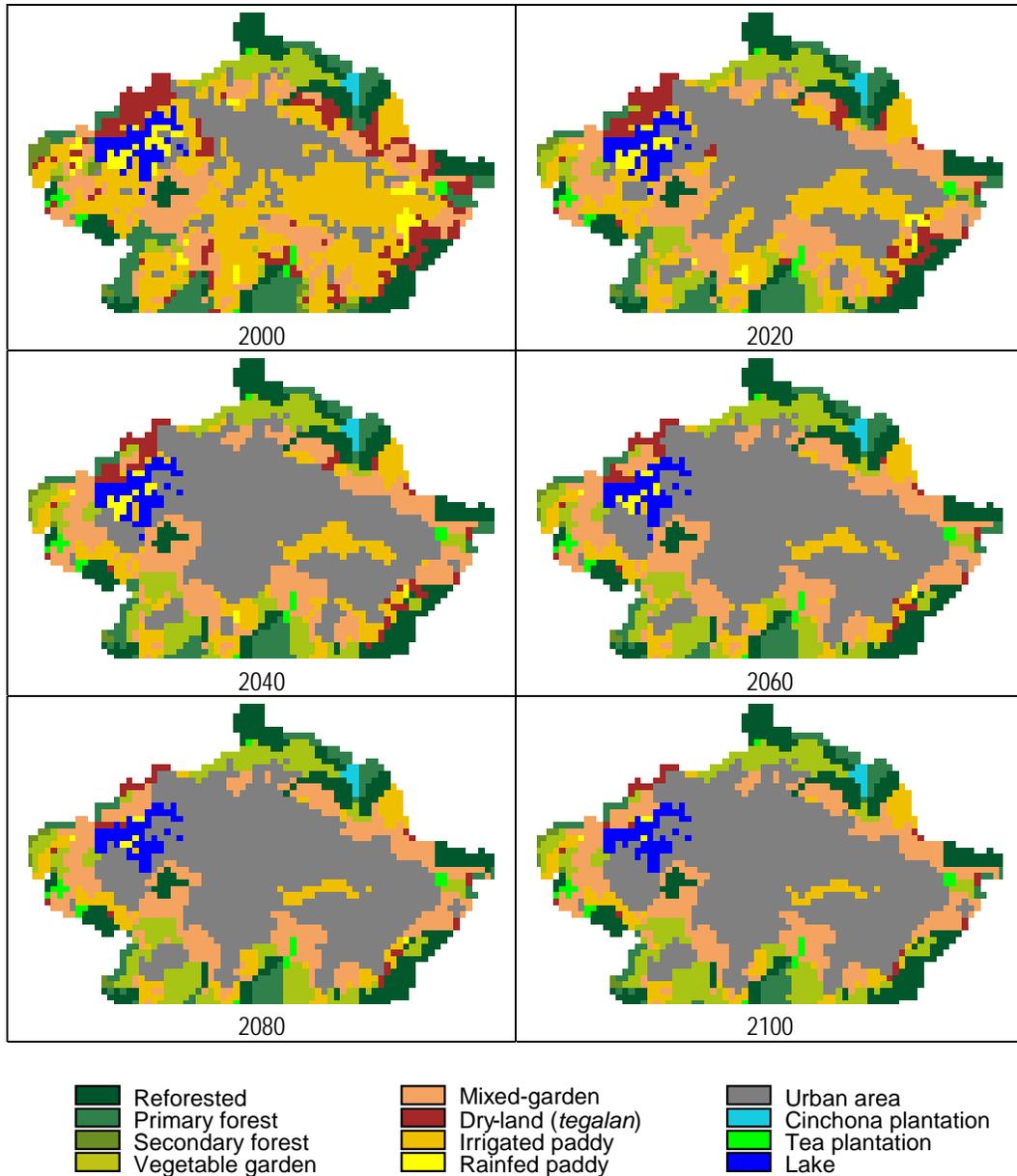
The integrated system allows a spatial analysis for examining the variation in the runoff resulting from the land use change and climate change. This spatial analysis can be performed because the computation in the integrated system is on a cell-by-cell basis. Fig. 12 shows changes in average annual volume of runoff (in %) relative to the baseline, with the time frame set to 2050. It shows distinct local variations of runoff under various land use change scenarios. In general, the pro-industrialisation scenario causes the largest local variations, followed by the business-as-usual pattern. The pro-agriculture scenario shows an increase in the runoff mainly by the boundary of the basin, which is mostly the result of conversion of forest to agricultural land. The ecological concern policy scenario shows no changes in the Northern Bandung region. The change in the runoff mainly occurs in the centre of the basin. The result of this spatial analysis of runoff shows the importance of land use as part of an integrated river management, that is by controlling the runoff locally in order to manage the entire streamflows.

## 5. Limitations

The model to produce scenarios of the land use pattern changes is static in nature. The changes depend on fixed rules and conditions, which remain the same throughout the whole process of land use change in the model. The growth in the urban area, for example, will decrease because during the growth process, it will encounter many restricting boundaries and factors such as slope, elevation and forest. The main road, which promotes urban growth and influences the direction of growth will also be less important because the distance between the main road and areas where the urban areas may expand has increased. Unless there is a change in rules, or additional main roads, the expansion of the urban area will terminate with time.

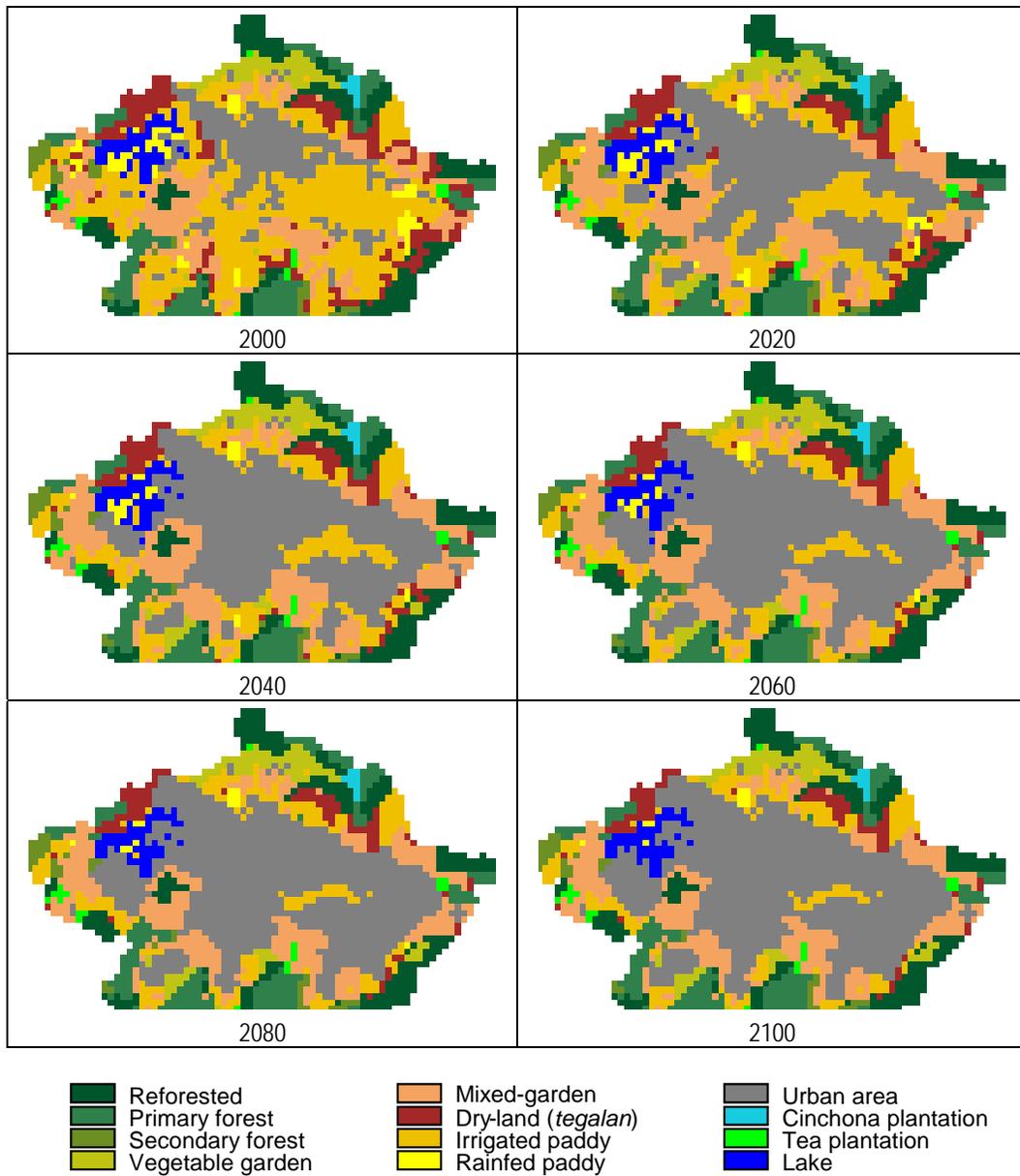
The whole process for generating the scenarios requires repeating procedures and processing for each land use type. This can be done quickly when a kind of SQL (sequence query language) or Macro programming language is available in the GIS package. This study use *script*, which is a kind of SQL provided by ILWIS Version 3.0. A script is a series of commands, calculations and expression that are predefined in a list. These are consecutively executed when the script is run, and this script can save a lot of time when dealing with frequently occurring processing. Some GIS packages may not have this capability that make the whole processes becomes time consuming.

BUSINESS-AS-USUAL



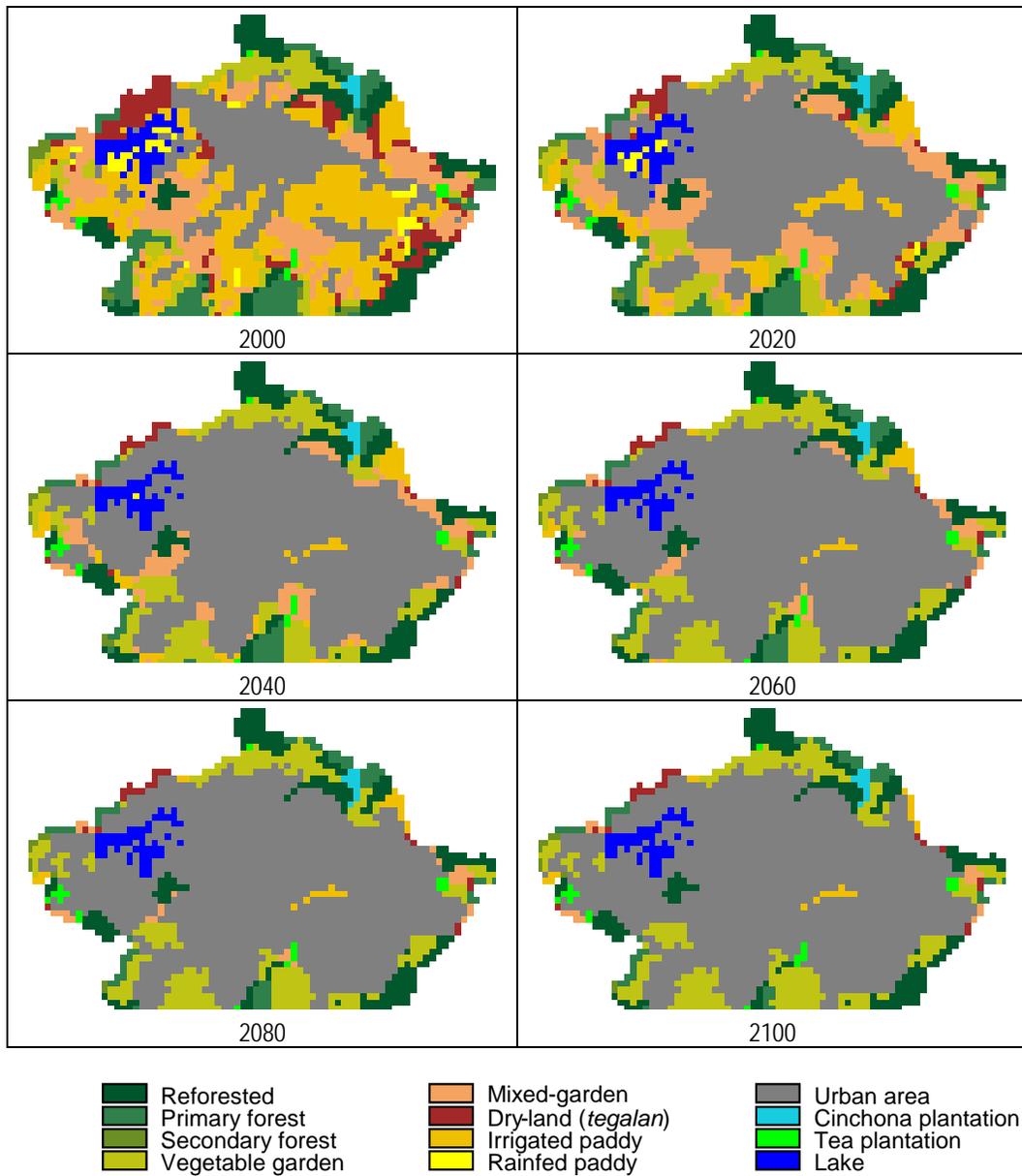
**Fig. 6** Change in the land use pattern under a business-as-usual scenario over a time series from the year 2000 to 2100, with a 20-year intervals.

ECOLOGICAL CONCERN



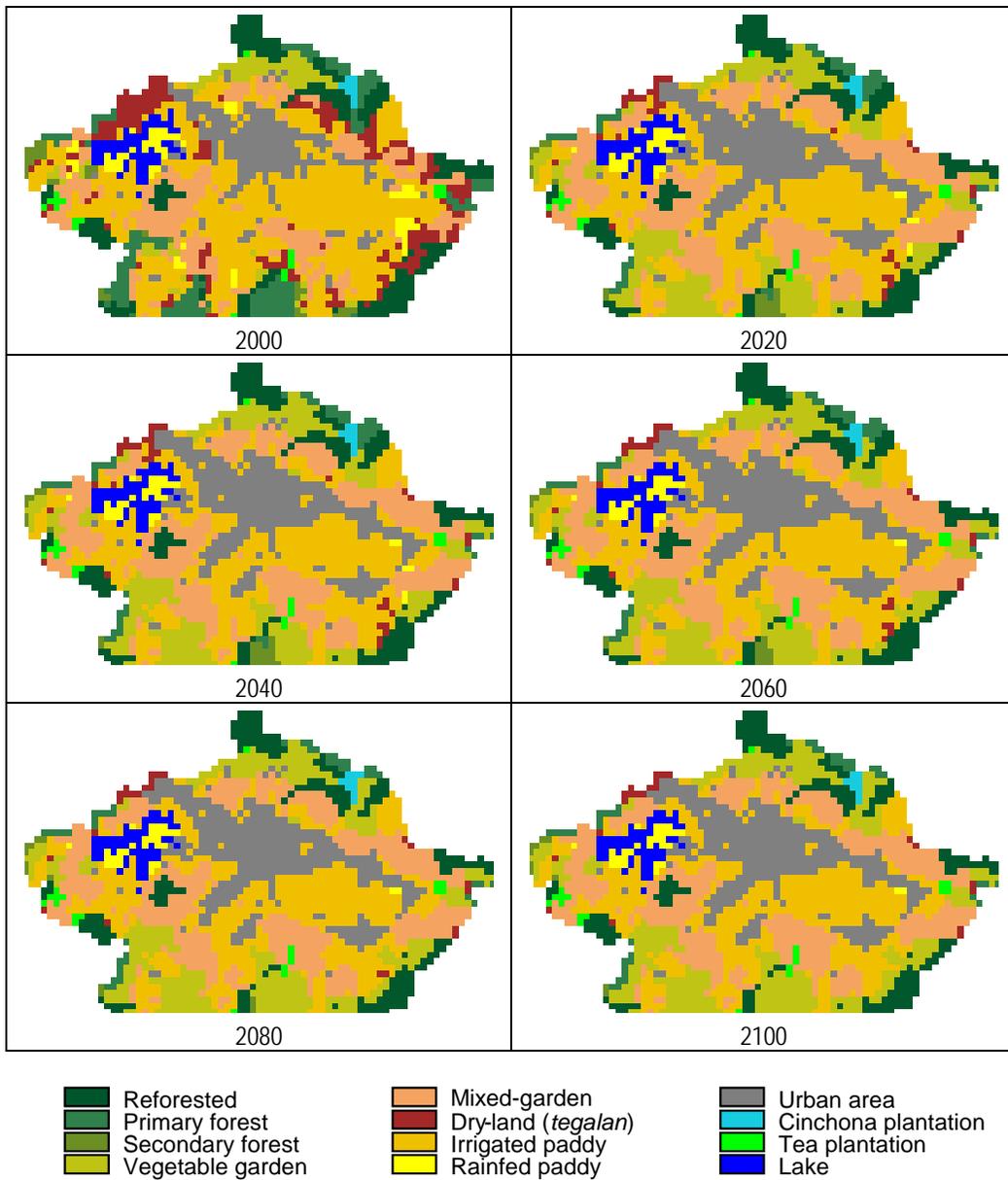
**Fig. 7** Change in the land use pattern under an ecological concern scenario over a time series from the year 2000 to 2100, with a 20-year intervals.

PRO-INDUSTRIALISATION

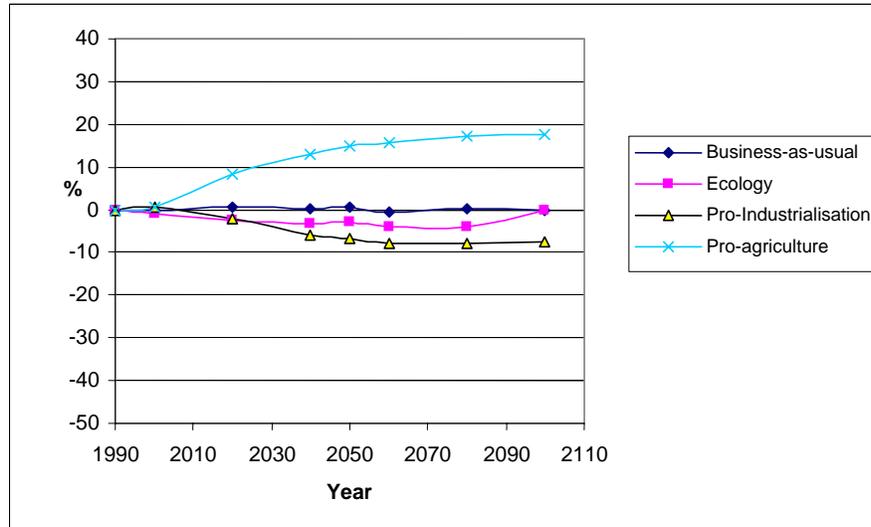


**Fig. 8** Change in the land use pattern under a pro-industrialisation scenario over a time series from the year 2000 to 2100, with a 20-year intervals.

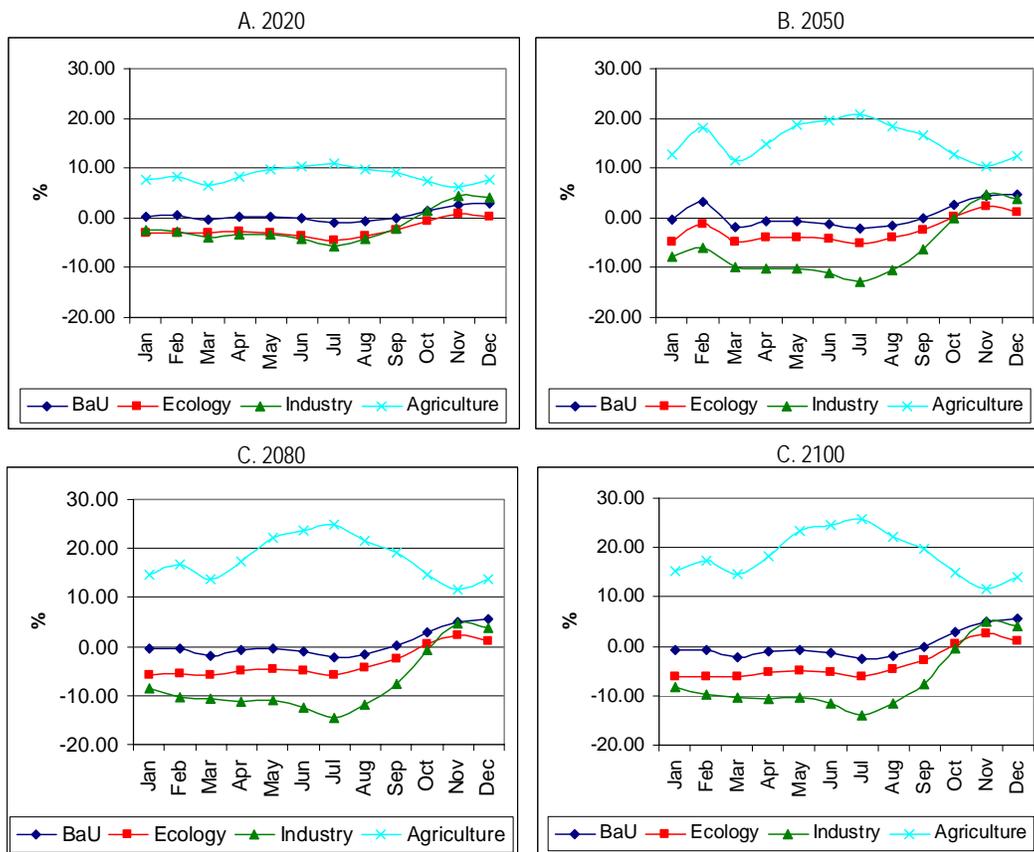
PRO-AGRICULTURE



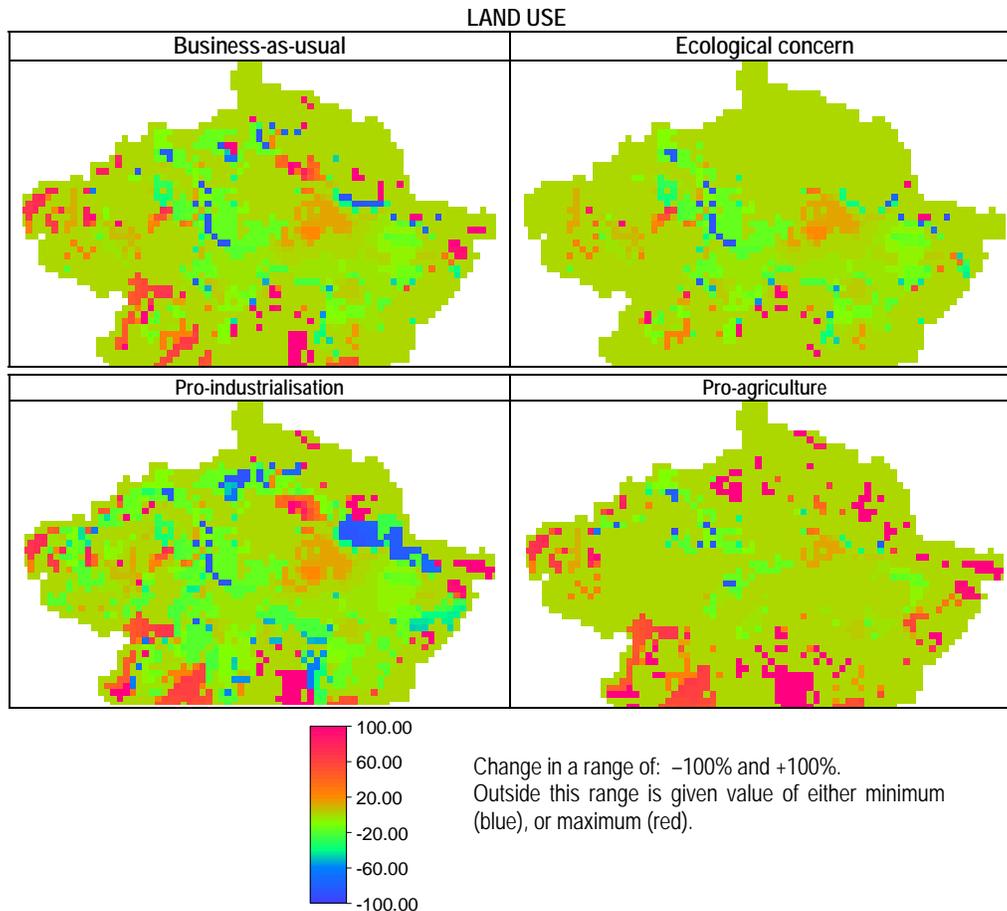
**Fig. 9** Change in the land use pattern under a pro-agriculture scenario over a time series from the year 2000 to 2100, with a 20-year intervals.



**Fig. 10** Percentage of changes in annual discharge relative to the baseline as the result of changes in land use patterns.



**Fig. 11** Percentage changes in monthly discharges relative to the baseline under various land use change scenarios.



**Fig. 12** Spatial variation in runoff resulting from various land use change scenarios in 2050.

## 6. Conclusions

This paper has introduced a method to generate a spatially explicit and time-series land use change patterns under various policy oriented scenarios. The method is conducted on a computer based GIS and uses the automata cellular principle. The procedure involves several steps: identifying the transitional rules and understanding the distribution behaviour of each land use type; defining physical factors and land use related weighting parameters, creating weighted maps; and processing. The scenarios of land use changes can be created by adjusting the weighting parameters used by the reference scenario in order to fit the conditions as wished or given by the regulation.

The implementation of the integrated system INDOCLIM in the study area using four selected policy-oriented scenarios (business-as-usual, ecological concern, pro-industrialisation, and pro-agriculture) shows the significance of land use change patterns on the streamflows. It demonstrates the variation of changes in the annual yield and seasonal variability of streamflows under various land use change scenarios, of which the greatest yield is obtained under pro-agriculture scenario and the lowest under pro-industrialisation scenario. In addition, the spatial variation of runoff resulting from various land use change scenarios can help to understand further the role of land use change on the local runoff that gives an opportunity in managing the streamflows through land use, including decision-making for determining areas that need to be conserved or restored as recharge zones for better condition of streamflows.

The structure of the integrated system INDOCLIM that put the land use change patterns off-line as library files, together with the method to generate the spatially explicit land use change patterns that has been introduced in this paper, give flexibility to create scenarios of land use change patterns according to the users' need. This flexibility gives an opportunity for assessing the possible impact of land use related policies, that is to examine whether those

policy leads to land use patterns that create a better or worse hydrological condition. This is believed as an important task that has to be done in a development planning.

In comparison to other spatially explicit land use models such as the dynamic spatial simulation model, this method to generate land use change scenarios is simpler and less data demanding. One of limitations of this method is that the transition rules and driving factors are fixed for the whole period, which is not the case in the real world. The static nature of this method causes the rate of change of land use reduced and may terminate with time. Despite having this kind of limitations, this method is good enough to create spatially explicit and time-series land use change patterns under various scenarios for the integrated system. Furthermore, these land use change patterns are generated by using a common commercially available GIS.

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