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RESEARCH ARTICLE

# Rural–Urban Transformation and Landuse Dynamics in Gunungpati on the Northern Flank of Mt. Ungaran, Semarang, Indonesia

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**Abstract**. Most of the northern flank of Mt. Ungaran is subject to intensive land occupation that makes landuse change inevitable. The research objectives of this study were to examine the spatial patterns of land-use dynamics from 1997 to 2018 and to analyze their impact on the rural–urban structure of Gunungpati sub -district using on-screen digitation. Rural–urban structure was analyzed based on landuse composition by area in each village. This research revealed that forest areas and paddy fields were decreasing year by year. Over the study period of 21 years, Gunungpati experienced deforestation of 1,777 ha and increase in built-up area of 1,295 ha, forcing shifting in rural structure. Most villages that were categorized as rural frame zones in 1997 had changed into urban–rural frame zones by 2018. This situation must be controlled, since much of Gunungpati territory plays a significant role as a groundwater recharge zone for the Semarang lowland area.



## 1. Introduction

The northern flank of Mt. Ungaran is facing significant increase in habitation due to the lack of available land in the Semarang lowland area Handayani, W., & Rudiarto, I. (2014), Sejati, A. W., Buchori, I., & Rudiarto, I. (2019). Prior to the 1990s, the northern slope of Mt. Ungaran was predominantly rural in structure, featuring dense vegetation cover and limited built-up areas. However, in 1992 this situation began to change following the construction of a state university in Semarang, a city located in the Gunungpati sub-district. This was followed by other development, such as the construction of roads, buildings, and other public infrastructure. Thousands of students arriving from other areas has had impacts on local inhabitants' livelihoods, for example farmers becoming boarding house owners. As a consequence, a great deal of agricultural land has been converted into boarding houses and shopping areas. Moreover, easier access to UNNES (Universitas Negeri Semarang) is likely to lead to land clearing on hills for residential construction. The changing rural structure arising from this land conversion is of concern because of the area's function as a groundwater recharge area which must be conserved Mortoja, M. G., & Yigitcanlar, T. (2020). This rapid and extensive development must be continuously monitored, because it will have impacts on hydrological behavior in both uplands and lowlands Delgado, M. I., Carol, E., & Casco, M. A. (2020). Several consequences will follow if the area of Gunungpati sub-district is not well managed, since it is included in the buffer zone category for the Semarang urban area Semarang Municipality (2011). The buffer zone has crucial roles in biodiversity protection [Thomas, C. D., & Gillingham, P. K. (2015), groundwater preservation [Balha, A., Vishwakarma, B. D., Pandey, S., & Singh, C. K. (2020), microclimate control [Barber, C.V., Miller, K.R. and Boness, M. (eds). (2004), and

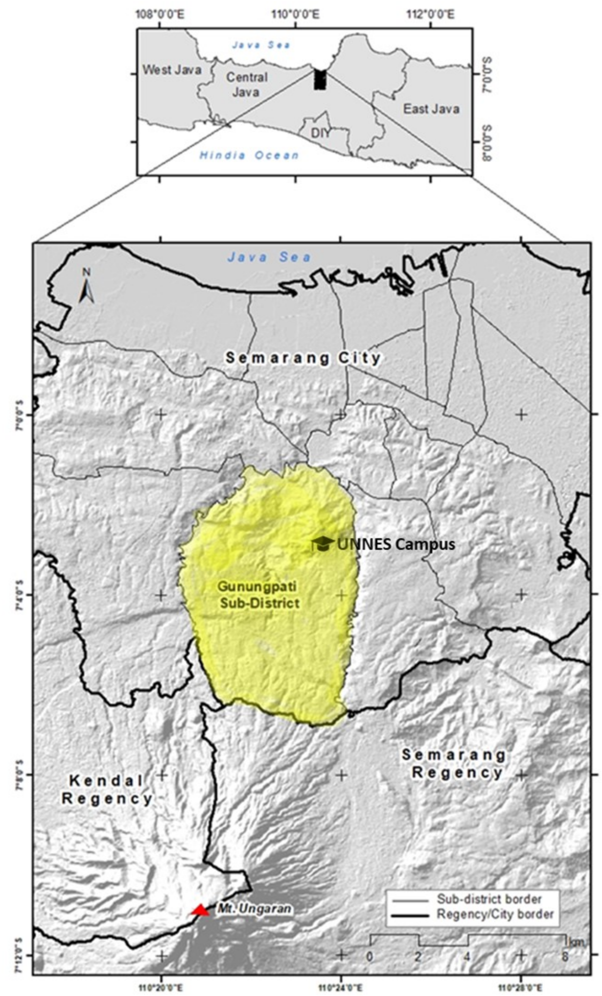



Figure 1. Position of Gunungpati sub-district and UNNES campus on the northern flank of Mt. Ungaran

overland flow stabilization Ferreira, C. S. S., Mourato, S., Kasanin-Grubin, M., Ferreira, A. J. D., Destouni, G., & Kalantari, Z. (2020).

Geographically, Gunungpati sub-district (Figure 1) covers an area of 60.84 square kilometers and mostly lies at about 200 meters above sea level. The landuse mapping conducted by the National Geospatial Agency in 1997 showed that 65% of this area was forested and 14% was built-up. There were 28,361 inhabitants living in the area in 2015 with population growth of 1,665 in that year (BPS, 2015). It forms part of the Semarang upland, is situated at the foot of the slope of Mt. Ungaran, and has a hilly morphology.

The development of built-up areas on the slope of Mt. Ungaran can be detrimental to the hydrological balance of the upstream area and may result in flood and drought Marti, J., and Ernst, G. (2005), Chester D.K., Duncan A.M. (2018), Panahi, A., Alijani, B., and Mohammadi, H. (2010), Sushanth, K., Bhardwaj, A. (2019). Analysis of the changing pattern of landuse using the terminology of spatial structure is needed to support protection against and mitigation of environmental damage that could cause future disasters

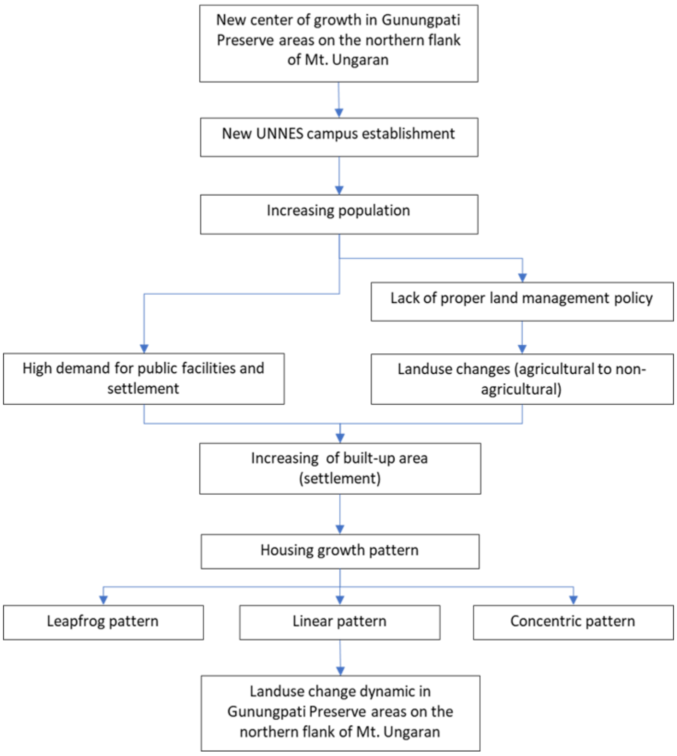



Figure 2. Research flowchart

Kundzewicz, Z. A., Budhakooncharoen, S., Bronstert, A., Hoff, H., Lettenmaier, D., Menzel, L., Schulze, R.(2002), Zipper, S. C., Keune, J.,and Kollet, S. J. (2019). Landuse changes can easily be identified using remote-sensing image technology [Mokhtari D.E., Douaoui A., Yahiaoui I., Guerziz H. (2018). Study of landuse changes and their effects on the environment in the whole area of Semarang city have been previously conducted S Subiyanto and L Fadilla. (2018). However, the previous research worked at the medium scale using Landsat Enhanced Thematic Mapper (ETM) medium-resolution satellite images as its data source. Meanwhile, detailed investigation of landuse changes in Semarang is still limited Dewi, D.I.K.,Anita R. R., and Pangi. (2016), Siregar, V and Alan, F. (2016). Using a combination of high-resolution imageries over a period of 21 years from 1997 to 2018 as its research flowchart (Figure 2), this study attempts to analyze the changes of landuse in the hilly area of Semarang located in Gunungpati sub-district and its implications for regional structure changes.

Table 1. Data acquisition

| Source | Year | Resolution (m) |
|---|---|---|
| Aerial photography | 1997 | 3 |
| Ikonos | 2000 | 4 |
| QuickBird | 2006 | 2.4 |
| SPOT-5 | 2010 | 5 |
| Sentinel-2A | 2018 | 10 |

## 2.Methods

The analysis of the landuse change pattern was conducted using data for the period 1997 to 2018. We used a combination of aerial photographs and various medium- to high-resolution satellite images for landuse interpretation (Table 1). We used multiple sources of satellite imageries because of the limited geospatial data availability. To resolve that issue, we used various satellite imageries with different spatial and temporal resolution.

Considering various resources of the satellite imageries with different spatial resolutions, we used the lowest spatial resolution to determine the landuse changes. Hence, we concluded that Sentinel-2A is the main consideration with 20 m for the minimum detachable size. By using Sentinel-2A, the optimum mapping scale can be calculated as follows:

**Map Scale = Raster resolution (in meters) * 2 * 1000 ….. (1)**

This study emphasized field survey by performing sampling in each of the landuses. The sampling technique in this study developed the Fitzpatrick Lins method, as follows:

$$N = Z^2(p)(q)/E^2 \quad (2)$$

N = sampling size
Z = normal standard deviation (= 2)

p = expected accuracy
q = 100 - p
E = accepted error

Since the accuracy level should be 90% and accepted error is equal to 10%, so

$$N = \frac{2^2 x 90 x 10}{10^2} = 36 \text{ sample points} \quad (3)$$

The 36 sample points were distributed into five landuses (built-up, forest, agriculture, and garden) and developed by using the formulation as follows (Muhaimin, 2014):

$$ni = \frac{Ni}{N} x\ n \quad (4)$$

ni = sampling size in land cover i
Ni = area of land cover i
N = total area of the study (Gunungpati Sub-district)
n = total of sampling size
Calculation result of the sampling size in each landuse was shown in Table 2.

Table 2. Sampling size distribution in each land cover

| Land cover | Land cover area (Ha) | Sampling |
|---|---|---|
| Forest | 2016 | 13 |
| Built-up area | 1383 | 10 |
| Agricultural | 1065 | 8 |
| Garden | 548 | 3 |
| Field | 344 | 2 |
| Total | | 36 |

Source: Study result, 2018

Table 3. Classification of rural and urban structure in developing countries Kundzewicz, Z. A., et al (2002)

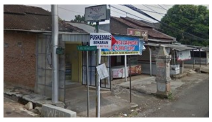
| Zone | Urban land | Rural land |
|---|---|---|
| Urban structure | > 75% to < 100% | < 25% to > 0% |
| Rural–urban structure | > 50 % to <75 % | >25 % to < 50 % |
| Urban–rural structure | < 50% to > 25%> | > 50% to < 75% |
| Rural structure | < 25% to > 0% | > 75% to < 100% |

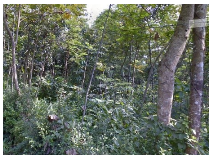
To define the spatial structure of the research location in each year, identification of types of landuse was conducted using digital on-screen techniques based on eight image-interpretation elements—color, shape, size, texture, pattern, shadow, site, and association—combined with local knowledge and random survey to validate the interpretation. The landuse map output in this research is at a medium scale of 1:25,000, reflecting the availability of various data sources. The medium scale of the output mapping was chosen to accommodate detailed information from various high-resolution remote-sensing imageries, namely aerial photographs, Ikonos, Quickbird, SPOT-5, and Sentinel-2A. Five types of landuse are identified in the study area—forest, built-up land, paddy field, mixed garden, and dry land. The analysis of landuse change which was the focus of this research encompassed yearly changes of area, spatial pattern, and structure.

Shift in rural–urban structure was analyzed using the landuse triangle continuum theory developed in Indonesia Yunus, H.S. (2008). The theory classifies regional structure into four zones based on the percentage of urban and rural land in particular areas (Table 3). Urban land is all built-up landused for non-agricultural functions, such as residential areas, shopping areas, government buildings, and public facilities, while rural land is used for agricultural purposes, i.e., paddy field, garden, dry land, and forest. Assessment of spatial structure and analysis were conducted in every village in Gunungpati sub-district.

Determination of urban physical pattern in this study follows the model according to Northam Yunus, S.H. (1994), in which urban physical distribution or housing growth is

Table 4. Result of Field Survey

| X Coordinate | Y Coordinate | Interpretation Result | Field Survey Result |
|---|---|---|---|
| 432723 | 9221245 | Built-up area |  |
| 433183 | 9220395 | Built-up area |  |
| 433148 | 9219915 | Built-up area |  |
| 433476 | 9220047 | Built-up area |  |
| 433441 | 9219812 | Built-up area |  |
| 433419 | 9210446 | Built-up area |  |
| 433366 | 9219279 | Built-up area |  |
| 433311 | 9218985 | Built-up area |  |
| 433622 | 9218730 | Built-up area |  |
| 433343 | 9218393 | Built-up area |  |
| 431813 | 9218094 | Agricultural |  |
| 431756 | 9217114 | Agricultural |  |
| 431065 | 9216967 | Agricultural |  |

| | | | |
|---|---|---|---|
| 430476 | 9217061 | Agricultural |  |
| 429813 | 9217398 | Agricultural |  |
| 428331 | 9218390 | Agricultural |  |
| 431056 | 9216954 | Agricultural |  |
| 429715 | 9218783 | Agricultural |  |
| 430441 | 9215649 | Garden |  |
| 430859 | 9214613 | Garden |  |
| 432614 | 9222704 | Garden |  |
| 428386 | 9218515 | Field |  |
| 429677 | 9218490 | Field |  |
| 430416 | 9215797 | Forest |  |
| 433395 | 9216652 | Forest |  |
| 431385 | 9222454 | Forest |  |
| 430660 | 9223164 | Forest |  |
| 430962 | 9222906 | Forest |  |
| 429247 | 9220697 | Forest |  |
| 428994 | 9220631 | Forest |  |
| 429303 | 9221670 | Forest |  |
| 429818 | 9217978 | Forest |  |
| 430386 | 9218084 | Forest |  |
| 430598 | 9218325 | Forest |  |
| 428595 | 9217051 | Forest |  |
| 429085 | 9217559 | Forest |  |

Source: Research results.

Table 5. Confusion Matrix

| Survey Result \ Interpretation | Bu | Ag | Gr | Fi | Fo | Total | Omission (%) | Commission (%) | Mapping accuracy (%) |
|---|---|---|---|---|---|---|---|---|---|
| Built-up area (Bu) | 10 | 0 | 0 | 0 | 0 | 10 | 0.0 | 0.0 | 100.0 |
| Agriculture (Ag) | 0 | 7 | 0 | 0 | 0 | 7 | 0.0 | 12.5 | 87.5 |
| Garden (Gr) | 0 | 0 | 3 | 0 | 1 | 4 | 25.0 | 0.0 | 75.0 |
| Field (Fi) | 0 | 1 | 0 | 2 | 0 | 3 | 33.0 | 0.0 | 66.7 |
| Forest (Fo) | 0 | 0 | 0 | 0 | 12 | 12 | 0.0 | 7.6 | 92.3 |
| Total | 10 | 8 | 3 | 2 | 13 | 36 | | | |

Source: Research results.

Table 6. User Accuracy and Producer Accuracy Values

| Land Cover Type | User Accuracy (%) | Producer Accuracy (%) |
|---|---|---|
| Built-up area | 100.0 | 100.0 |
| Agricultural | 100.0 | 87.5 |
| Garden | 75.0 | 100.0 |
| Field | 66.0 | 100.0 |
| Forest | 100.0 | 92.3 |

classified as 1) concentric development pattern, in which the physical propagation of the city is equally distributed around the urban area, tends to be slow, and is characterized as a compact city; 2) linear development pattern (ribbon/linear/axial development), in which the physical spreading of the city follows the pattern of the road networks or rivers and is characterized by unequal distribution in each part of the urban development; and 3) leapfrog development, in which physical propagation of a city does not follow a particular pattern. Leapfrog development is also known as scattered development.

## 3.Result and Discussion

### Accuracy Test Result

In this study, the level of interpretation accuracy was measured by confusion matrix. Before the measurement, the field survey has done in 36 sampling point. Based on Table 4, there are 13 sampling points in forest area, 10 points in built-up area, 8 points in agricultural area, 3 points in garden area, and 2 points in field area. The result of field survey is as table 4.

Based on field survey result shown in Table 5, there are 10 built-up area sample points that correctly interpreted. In agricultural area, 7 of 8 sample points were correctly interpreted. In garden area, all three sample points were correctly interpreted. In field area, all two sample points were correctly interpreted. In forest area, 12 of 13 sample points are correctly interpreted. Those field survey results then inputted in the confusion matrix, as follows (Table 5 and Table 6).

Based on accuracy test of confusion matrix, the overall accuracy is 94.5% and the Kappa accuracy is 92.54%. These accuracy level had exceeded the 85% standard accuracy from USGS. The accuracy test was only processed in Sentinel-2A image in 2018. The reason was because the interpretation key used in all satellite images are all the same, so the accuracy test in one image could be applied for other images.

Based on Table 5, the lowest omission value is from agricultural, forest, and built-up areas, i.e., less than 0%. The largest omission value is from field area, 33%. The lowest commission is in garden, field, and built-up area, 12.5%. The largest commission value is from agricultural area, 12.5%. The highest mapping accuracy is in built-up area, 100%, and the lowest is in field area, 66.7%. Then, based on Table 6, the highest user accuracy is from agricultural, forest, and built-up area, 100%, and the lowest is from field area, 66%. The highest producer accuracy is from garden, field, and built-up area, 100%, while the lowest is from agricultural area, 87.5%.

### The spatial pattern of landuse change

Landuse change in Gunungpati sub-district from 1997 to 2018 is depicted in Figure 3 and Figure 4 following the optimum detachable size and mapping scale from the 10 m of spatial resolution. A negative trend was evident for forest and paddy fields, the areas of which tended to decrease annually. In contrast, built-up land, mixed garden, and dry land saw a positive trend, increasing every year (Figure 5). In 1997, 65% of areas in Gunungpati were forest and only 14% were built-up areas. The area of forest decreased to only 36% in 2018, similar in extent to the built-up areas. Built-up areas rose substantially, from 876 Ha in 1997 to 2,171 Ha in 2018, an increase of 148%. Agricultural activities in Gunungpati also changed from paddy fields to mixed gardens and dry land, with the area of mixed garden increasing 612% over the 21 years of the study.

These changes in landuse had impacts on spatial pattern, especially in the built-up areas. Based on the interpretation of satellite imageries, settlement development gradually changed from a leapfrog pattern in 1997 to a concentric settlement pattern (Figure 6). Leapfrog settlement shows as scattered small groups of urban development in the middle of a garden or forest. In the past, leapfrog settlement dominated, owing to most Gunungpati areas being forest and paddy. Subsequently, small group settlements grew larger and formed concentric settlements. Concentric settlement in Gunungpati tended to grow in flat topography, on lowlands and uplands, and around UNNES, in Sekaran village.

The main cause of landuse change is the annual growth in population, with human need for space resulting in deforestation to enable the building of residential areas. The improvement and opening of new roads and the relocation of the state university in 1990 also contributed to the development of built-up areas. Furthermore, the lowland of Semarang experienced urban problems such as crime, flooding, traffic congestion, noise, and air pollution. In other

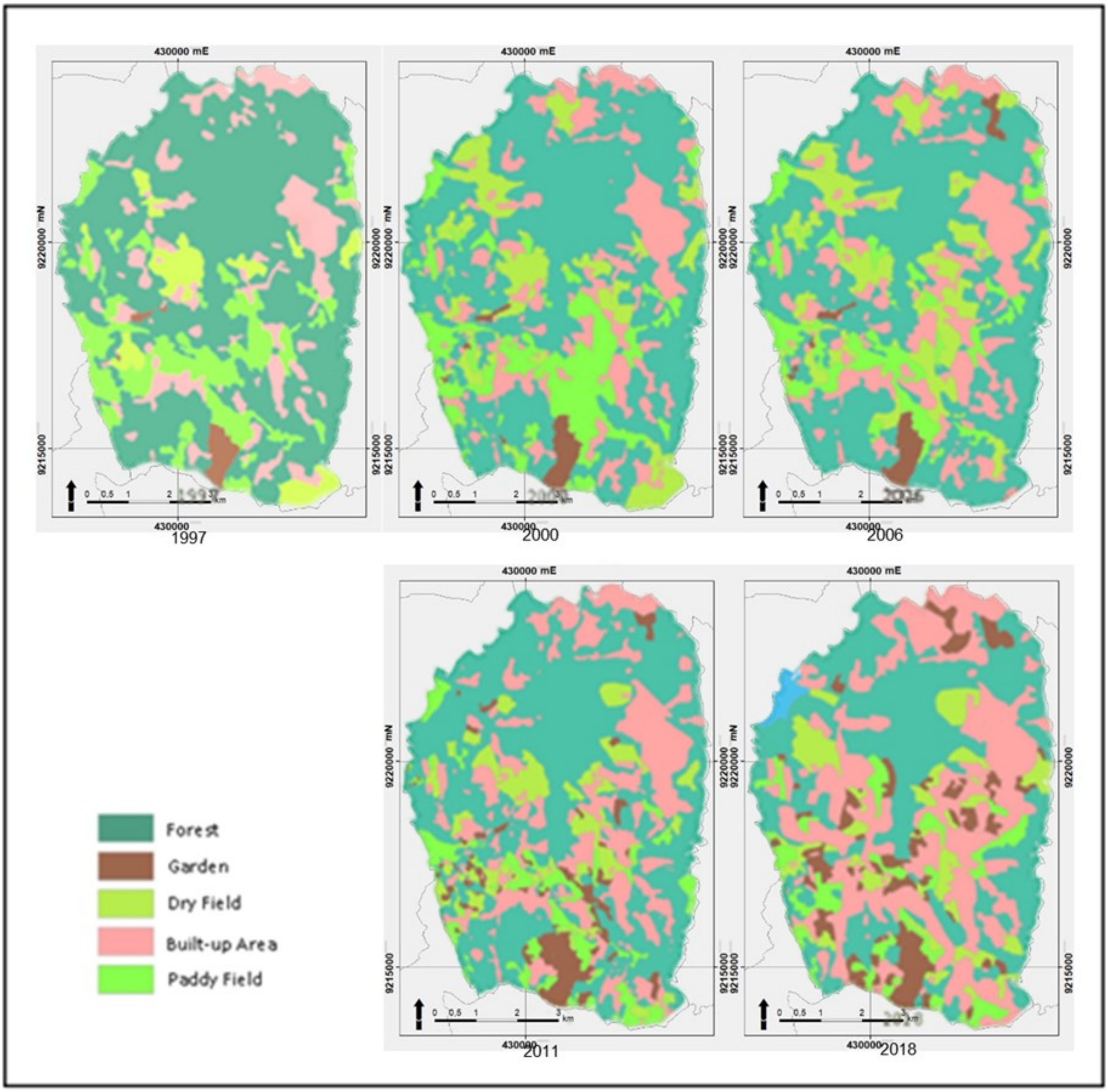



Figure 3. Landuse change in Gunungpati sub-district: 1997–2018.

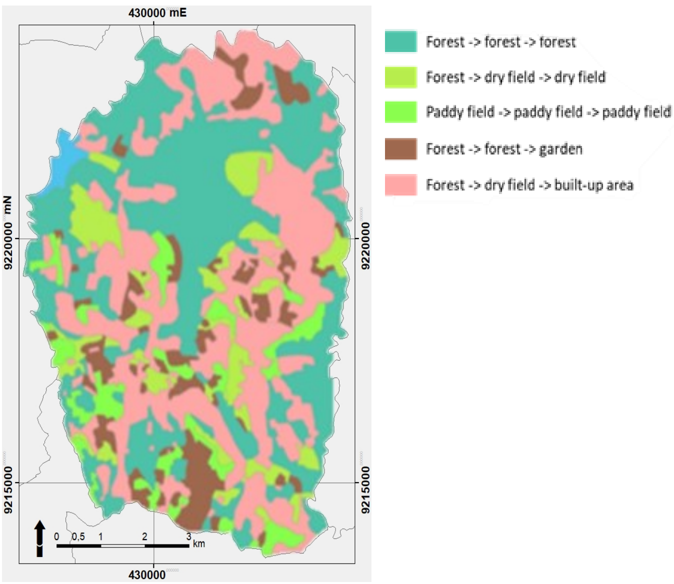



Figure 4. Landuse change trajectory in Gunungpati sub-district: 1997, 2006, and 2018.

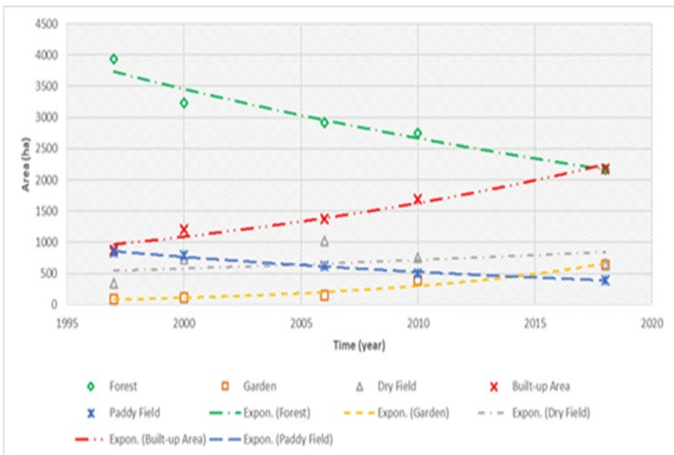



Figure 5. Landuse change pattern in Gunungpati sub-district.

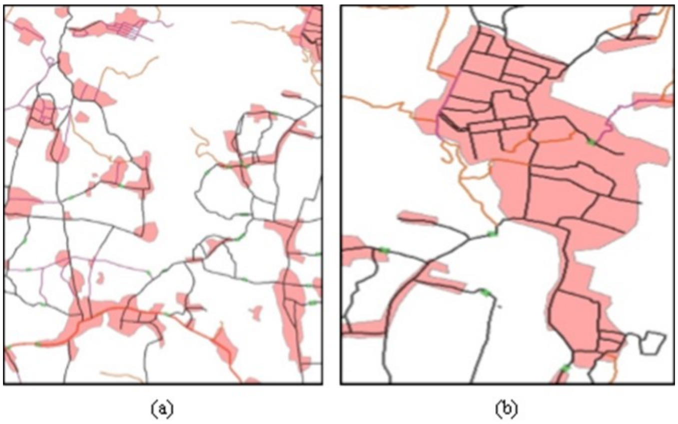



Figure 6. Leapfrog pattern dominated in the 1997 settlement area, then developed into concentric pattern in 2018

Table 7. The rate of land-use changes in Gunungpati sub-district

| Period | Landuse change | | Landuse change, annual rate | |
|---|---|---|---|---|
| | % | ha | % | ha |
| 1997–2000 | 24.49 | 1,490 | 8.16 | 123 |
| 2000–2006 | 16.37 | 996 | 2.73 | 27 |
| 2006–2010 | 18.11 | 1,102 | 4.52 | 50 |
| 2010–2018 | 25 | 1,519 | 3.12 | 47 |
| 1997–2018 | 72 | 4,379 | 3.42 | 150 |

Table 8. Total area of change in each landuse type in Gunungpati sub-district

| Period | Area (ha) | | | | | Total area (ha) |
|---|---|---|---|---|---|---|
| | Forest | Mixed garden | Dry field | Built-up area | Paddy field | |
| 1997–2000 | 703 | 20 | 395 | 330 | 42 | 1,490 |
| 2000–2006 | 325 | 41 | 284 | 173 | 173 | 996 |
| 2006–2010 | 171 | 238 | 260 | 313 | 120 | 1,102 |
| 2010–2018 | 578 | 252 | 104 | 479 | 106 | 1,519 |
| 1997–2018 | 1,777 | 551 | 315 | 1,295 | 441 | 4,379 |

locations, landuse changes resulting from growth in built-up areas have been reported to increase the surface-water runoff that is responsible for flooding Khare, D., Patra, D., Mondal, A. et al. (2014).

The availability of plots of land at affordable prices has led people to choose to live on the upland area, despite its distance from the city center. As well as the impacts of conversion of rural land into residential areas, the risk of crop failure and low profit returns might also have resulted in decrease in the area of paddy fields in Gunungpati. People may have chosen to cultivate their land as mixed garden and/or dry land as these did not rely so heavily on water availability and did not need to be as intensively cultivated as paddy fields.

## The rate of landuse change in Gunungpati sub-district

The change rate of landuse in Gunungpati from 1997 to 2018 was 3.42% per year (Table 7) resulting in deforestation mainly for creation of built-up areas. In other words, the change of landuse annually experienced was 150 ha. The decrease rate of forest was 85 ha/year, while the increase rate of built-up areas was 62 ha/year. In terms of agriculture, the rise of garden areas was 26 ha/year, while the decrease of

Table 9. Spatial structure of land utilization in the northern part of Mt. Ungaran 1997–2018

| Village | 1997 | 2000 | 2006 | 2010 | 2018 |
|---|---|---|---|---|---|
| Jatirejo | 1 | 1 | 1 | 1 | 1 |
| Ngijo | 1 | 1 | 1 | 1 | 1 |
| Sukorejo | 1 | 2 | 2 | 2 | 2 |
| Sadeng | 1 | 1 | 1 | 1 | 2 |
| Kandri | 1 | 1 | 1 | 1 | 2 |
| Sekaran | 2 | 2 | 2 | 2 | 2 |
| Pungangan | 1 | 1 | 1 | 1 | 2 |
| Kalisegoro | 1 | 1 | 1 | 1 | 1 |
| Patemon | 1 | 1 | 1 | 2 | 2 |
| Nongkosawit | 1 | 1 | 1 | 2 | 3 |
| Cepoko | 1 | 1 | 1 | 2 | 2 |
| Mangunsari | 1 | 2 | 2 | 2 | 2 |
| Gunungpati | 1 | 1 | 1 | 1 | 2 |
| Pakintelan | 1 | 1 | 2 | 2 | 2 |
| Plalangan | 1 | 1 | 1 | 1 | 1 |
| Sumurejo | 1 | 1 | 1 | 1 | 2 |

Note: 1, 2, 3 and 4 represent rural frame zone, urban–rural frame zone, rural–urban frame zone, and urban frame zone respectively.

paddy field areas was 21 ha/year. Dry land saw the lowest rate of landuse change of 15 ha/year.

Forest and built-up areas experienced the most dynamic landuse change in Gunungpati sub-district (table 8). Based on trend and change rate, forest is likely to decrease in the future such that if forest conservation law is not enforced Gunungpati is predicted to have no forest by 2048, having been converted into built-up areas or mixed gardens. With the advancement of technology in the field of construction, the intervention of built-up areas is clearly seen from the large number of residential areas constructed on steep slopes. Beside built-up areas, landuse change also derives from conversion to plantations which are deemed to have higher economic value.

Change in landuse has led to shift in regional structure in Gunungpati. The analysis results for 16 villages show a regional structural change from rural frame zone into rural–urban frame zone (Table 9). The number of villages having rural–urban frame zone characteristics rose annually. A significant increase occurred in 2010, when 44% of the villages in Gunungpati had rural–urban frame zone characteristics resulting from the increase of built-up areas. This proportion reached a peak of 67% eight years later. One village even shifted to an urban–rural frame zone. Villages with urban–rural zone structures generally had main roads and/or were located near the construction site of UNNES.

Regional structure shift from rural frame zone to rural–urban zone will be likely to have negative impacts on groundwater recharge areas. Increase in built-up areas will decrease the amount of water absorbed by the soil which can then fill the aquifer system Karakayaci Z. (2016). Consequently, water shortage is likely in the dry season. More areas in Semarang have been reported as experiencing drought since 2012 and this increase has been directly proportional to the extensive change in regional structure in Gunungpati sub-district. In addition, the decrease in forest areas has also contributed to higher intensity of flooding on lowland areas. The Garang river in Semarang has an enormous natural potential for flooding owing to the proximity of its upstream and downstream areas. Rise in overland flow due to deforestation in the study area will certainly increase the level of flood danger in Semarang. Due to the complicated hydrological problems developing, local governments started to construct a reservoir in the western part of Gunungpati in 2009 to control flooding in the rainy season and to store water for the dry season.

## 4.Conclusion

Change of landuse in Gunungpati has impacted on shifting regional structure and on geophysical environmental balance. The increase of non-agricultural land from 1997 to 2018 led to the change from rural structure to peri-urban structure. Based on our findings in terms of change-rate trends, landuse will acquire an urban framework in the future. The urbanization of areas which function ecologically as recharge areas will be detrimental, because land surfaces covered by concrete and asphalt will reduce the quantity of groundwater. Hydrological balance in the upstream area will be negatively affected and the consequences will be various hydrometeorological disasters. Laws and regulations on spatial planning should be enforced to protect forest and agricultural land in the area from development. Disaster-mitigation-based city governance is also required to reduce the risk of loss and to realize sustainable development in the future.

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