# CONTAMINATION VULNERABILITY ANALYSIS OF WATERSHED FOR WATER QUALITY MONITORING

*Study in Gajahwong Watershed Yogyakarta Province*

By:

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*ABSTRACT*

*This research is an early step to determine the location of rain gauge station for artificial neural network modeling. The implementation of this model is very useful for water quality monitoring. The objectives of this study are: 1) to study the distribution of watershed parameter, that are average annual precipitation, land use and land-surface slope, 2) to conduct vulnerability analysis of watershed contamination, 3) to determine the location of rain gauge station.*

*The study was performed by weighing and rating method of watershed parameters. The vulnerability degree of watershed to contamination is presented as vulnerability index. This index is determined by overall sum of all multiplication between score and weigh number of each parameter. All data manipulation and data analysis were performed by using Geographic Information System (Arc View version by 3.2). The vulnerability of watershed contamination map had been generated using overlay operation of parameters.*

*The results show that vulnerability index are varies between 10 up to 40 intervals. Hence, the indexes were categorized into three levels of watershed vulnerability, namely low (10 – 20), moderate (20 – 30) and high (30 – 40). It is found that the study area covered more by high vulnerability of watershed to contamination. The zoning of watershed vulnerability meant to determine the rain gauge location. There are three rain gauge stations on the area that they are in a high vulnerability level, whereas the other vulnerability level area has one rain gauge station. Each level of vulnerability area is able to represent the source of contaminant that it maybe influence the water quality of Gajahwong river.*

*Key words : vulnerability, contamination, watershed*

## INTRODUCTION

Clean water is a serious problem in urban society. Generally, the water resource of urban area is from the river. The problem in urban area is river water contamination. The development of river water monitoring model (Artificial Neural Network – ANN) became important. There are some steps for those modeling, i.e.: taking sample of river water in outlet of tributary, staff gauge installation for water level recording in outlet of tributary, rain gauge installation in each sub catchments area (Suprayogi, *et.al*, 2005)

This research is a beginning part of ANN modeling. Its focus is only in the vulnerability delineation for rain gauge installation. The rainfall is a transporting media to carry the contaminant into the river. The assumption is the high vulnerable area will contribute higher contaminant sources to the river than less degree of vulnerable area. Each rainfall data will be paired by river water quality data for the ANN modeling necessity.

The chemical composition of natural water is determined by many different sources of solute, including gases and aerosol from the atmosphere, weathering, and erosion of rock and soils, solution or precipitation reactions occurring below the land surface, and culture effects resulting from activities of man (Hem, 1970). River water quality changes rapidly than groundwater quality because the former is more open than the other. The river water is degraded when its quality parameters are changed beyond their natural variation by introduction or removal of certain substance. The degradation may impair the usefulness of water.

Contamination vulnerability concept of groundwater is introduced firstly than surface water vulnerability concept. The concept of groundwater vulnerability is based on the assumption that physical environment may provide some degree of protection to contamination entering groundwater (Vrba and Zaporozec, 1994). That is meant the intrinsic vulnerability. The physical characteristics are the depth to water table, recharge, lithology, soil, and hydraulic conductivity. Rosen (1994) conducted the vulnerability of groundwater to contamination research on Swedish using DRASTIC method. The other research that is conducted using DRASTIC was developed by Widyastuti (2004) to asses the groundwater to contamination. Ferreira (1997) distinguishes the term of groundwater to contamination and the pollution risk. The letter was not only based on the intrinsic vulnerability but also the sources of pollution.

There is no strict different concept between surface water and groundwater vulnerability. The rating and weight of watershed vulnerability parameters was different to groundwater vulnerability parameters. Eimers *et al* (2000) have done the research of watershed characteristics rating. The factors applied for determination of watershed characteristic ratings are average annual precipitation, land-surface slope, land cover or land use, and groundwater contribution. Different parts of the physical environment have varying capacities for attenuation contaminants.

Geographic Information System (GIS) (Burrough, 1986) is a tool that is used to collect, to save, to active, to transform, and to present of phenomena spatial data on the earth for special objectives. Besides, GIS can supply analysis range widely and spatially from geographically and non spatially data. The technically mapping could be done manually or computerize using GIS (Vrba and Zaporosec, 1994). Some vulnerability of groundwater to contamination researches is based on the GIS approach.

Gajahwong watershed is a sub watershed of Opak watershed that covered Sleman regency, Yogyakarta city, and Bantul regency. Each of the regions has some contributions to the Gajahwong river water quality. That is because each region has different land use. For example, Yogya city has more activities than the other regions. Those activities are settlement, industries, agriculture, hospital and public services. Gajahwong is one of the important rivers in Yogyakarta Province because of its function. It is used for drinking water sources (B class).

Based on these fact, this research has three main objectives : 1) to study the distribution of watershed parameter, which are average annual precipitation, land use and land-surface slope, 2) to analyze the contamination vulnerability of watershed , 3) to determine the location of rain gauge station.

## METHODS

This research applies the Point Count System Model (PCSMs) to evaluate the vulnerable of watershed. This model employs a numerical ranking system that assigns relative weight to various parameters of watershed. The watershed characteristic rating is based on a combination of factors that contribute to the likelihood that water will reach surface water by following the path of overland flow. The selected factors, which can be represented as spatial data layer in the Geographic Information System (GIS), include average annual precipitation, land-surface slope and land use. Each variable is given interval from 1 to 10, and further more each parameter has an interval of weight 1 to 3. A rating of 1 reflects a low contribution to inherent vulnerability and 10 reflects a high contribution. The most significant parameters have weight of 3; while the least significant parameters have weight of 1. Each factor and its rating and weight is listed on Tables 1 and 2. The rating for each interval is multiplied by weight for the parameter and the products are summed to obtain the final numerical score that provides relative measure of vulnerability. The simple formula is presented as follow:

$$VI = R_w R_r + T_w T_r + L_w L_r$$

where :

$VI$ = vulnerability index

$R_w$ = weights assigned to average annual precipitation

$R_r$ = ratings assigned to average annual precipitation

$T_w$ = weights for topography (land-surface slope)

$T_r$ = ratings for topography (land-surface slope)

$L_w$ = weights for land use

$L_w$ = ratings for land use

Data processing and analyzing had been done by using GIS, i.e. Arc/View software version 3.2. The each factor was mapped the overlaid to obtain the contamination vulnerability of watershed.

Table 1. Factors that contribute to the watershed characteristic rating (modified from Eimers, *et al.*, 2000)

| Factor | Relevance of the factor | Weight |
|---|---|---|
| Land-surface slope | The inclination, or change in elevation, of the land surface indicate the likelihood that precipitation will infiltrate or runoff | 1 |
| Average annual precipitation | The sources of water that travel overland to streams or lake | 2 |
| Land use | The type of land use influences the likelihood of potential non-point source contamination | 3 |

Table 2. Factors categories and rating for watershed vulnerability (modified from Eimers, *et al*., 2000)

| No. | Average annual precipitation categories (mm/year) | Rating |
|---|---|---|
| 1. | 1500 – 2000 | 5 |
| 2. | 2000 – 2500 | 7 |
| 3. | 2500 – 3000 | 9 |
| 4. | >3000 | 10 |
| No. | Land-surface slope (%) | Rating |
| 1. | <8 | 2 |
| 2. | 8 – 15 | 4 |
| 3. | 15 – 25 | 6 |
| No. | Land use | Rating |
| 1. | Water | 1 |
| 2. | Brush | 4 |
| 3. | Mixed garden | 5 |
| 4. | Row crop | 6 |
| 5. | Paddy field | 7 |
| 6. | Settlement | 8 |

## RESULT AND DISCUSSIONS

### Land-surface Slope

Land-surface slope determines the amount of precipitation to become overland flow and surface water or ponds storage. The relation between slope and the occurrence of overland flow has underscored by its effect on the water quality. Surface water is more vulnerable to contamination in areas of steeper surface slope. When all other factors are the same, precipitation infiltrates into the subsurface in areas characterized by low slope, whereas precipitation runs off land surface in areas which has a high slope. Slope in the research area was divided into three categories, i.e. less then 8 %, 8 to 15 % and 15 to 25 %. Most of the study area had slope less than 8 % and they covered Sleman regency, Yogya city and Bantul regency. Small part of study area had slope more than 8 % and lay on the Sleman regency or the upper of Gajahwong watershed.

### Average Annual Precipitation

The average annual precipitation represents the mass of water that becomes available for transport in a watershed. Precipitation is the sources of overland flow to stream or lake. It is assumed that the higher amount of the rainfall is the greater chance of the contaminant transported through the overland flow. The period of rainfall data selection was last ten years (1994 –2003). In study area, average annual precipitation varies from 1500 to more than 3000 mm. The average annual precipitation was categorized in increment of 500 mm, from 1500 to more than 3000 mm. The distribution of rainfall related to its topography, the upper stream received more than 3000 mm/years. Small part of the study area received about 2500 to 3000 mm/year. It also covered in the upper of watershed. The rainfall distribution in the middle part of Gajahwong watershed was 2000 to 2500 mm/years, and then in the lower stream was 1500 – 2000 mm/year. Average precipitation in the research area has a high categorized. The most of study area has average annual precipitation between 1500 to 2500 mm/year.

**Land use**

Land use describes human activities on the land surface. This factor represents the potential generation of non point-source contamination resulted from human activities. Land use also influences the percentage of precipitation that runs off as overland flow. Each land use type has different contribution to the water quality. It depends on the amount of waste that it might be produced from each activity. It is also shown on the Table 2. The land use was predict has a high contribution on stream contamination; it has a high rated. The data source of land use is derived from topographical map. There are six categories of the land use in the research area, i.e.: water (5 ha), brush (0,07 ha), mixed garden (111,8 ha), row crop (59,9 ha), paddy field (1891,83 ha) and settlement (2578,35 ha). The study area mostly covered by settlement and paddy field land use types. So, the land use in the study area has more contribution on the vulnerability level.

**Contamination Vulnerability of Watershed**

Contamination vulnerability of watershed is the rate of sensitiveness to be polluted. Spatial distribution of watershed vulnerability is obtained by overlaying all parameters map, i.e. land surface slope, average annual precipitation and land use. The map of contamination vulnerability of watershed is presented on Figure 1. The vulnerability index (VI) is an indication of watershed vulnerability level. Those index ranges from 10 to 40, and they are categorized into three classifications (see on Table 3).

The areas of high vulnerability categories is predominant, i.e. 3.203,393 ha (64,34%) in the research area. The moderate vulnerability category areas occupy an area at 1.645,324 ha (33,87%), while the low vulnerability areas is 8,693 ha (1.79%). The result showed that the river in the study area is vulnerable to contamination. This vulnerable is influenced mostly by land use. It is assumed that the greater settlement tend to produce more domestic waste. Besides, the average annual precipitation also has a high contribution. Most of the study area is covered by a high rainfall.

Based on the vulnerability level in the research area, rain gauge stations are installed. The distribution of rain gauge depends on the area of each vulnerability level. It is meant to be able to represent each vulnerability level area. There are three rain gauge stations that are installed in the high vulnerability areas, whereas in the other vulnerability levels there is one rain gauge station. Each rainfall data in each vulnerability degree in the study area will be paired by river water quality data for the ANN modeling necessity.

Table 3. Classification of Contamination Vulnerability in Study Area

| No | Vulnerability Index | Categories |
|---|---|---|
| 1. | 10 – 20 | Low |
| 2. | 20 – 30 | Moderate |
| 3. | 30 – 40 | High |

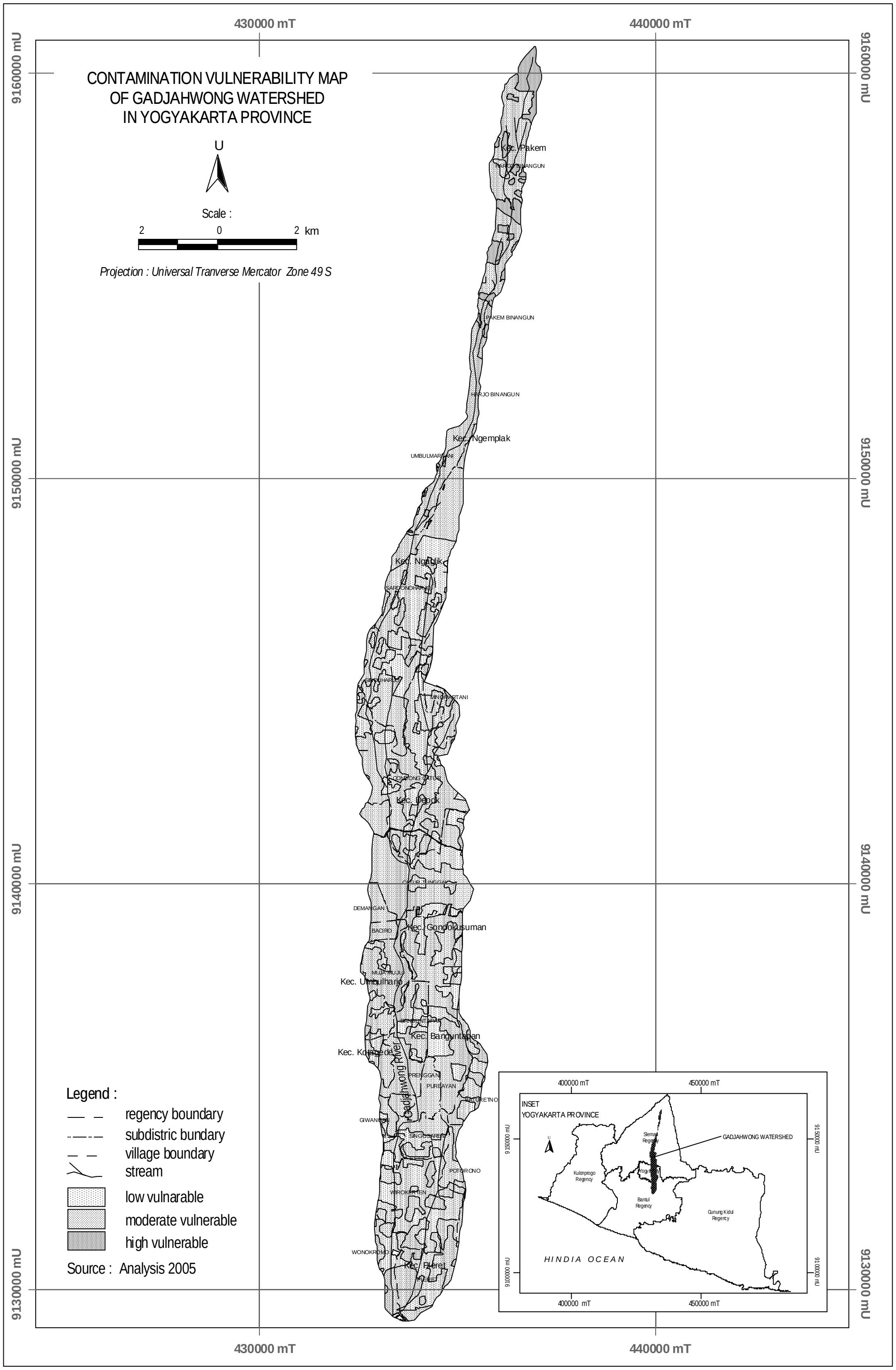


Figure 1. Contamination Vulnerability Map of the Study Area

## CONCLUDING REMARKS

The range of vulnerability index in study area is 10 – 40. They are divided into three categories, i.e. : low (10 – 20), moderate (20 – 30), and high (30 – 40). More than 50 % of the research area is categorized as high vulnerability. The areas of low vulnerability category are 8,693 ha (1.79%), moderate vulnerability category are 1.645,324 ha (33,87%) and high vulnerability category are 3.203,393 ha (64,34%). This vulnerable is influenced mostly by land use, and also the average annual precipitation. The installation of rain gauge station represents area of each vulnerability level. There are three rain gauge stations that are installed in the high vulnerability areas, whereas in the other vulnerability levels there is one rain gauge station.

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