Geology of Yogyakarta, Java: The dynamic volcanic arc city

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Abstract: Yogyakarta city, the capital of Yogyakarta Special Province, is situated at the southern part of the volcanic arc island of Java. The geology of the city and province is controlled by active plate tectonic phenomena such as the active volcano and active subduction of Indo-Australia oceanic plate below the Euro-Asian continental plate. The city and the province accordingly are prone to geohazards (landslides, floods, volcanic eruption and earthquakes) as well as eco-geological problems. Indeed, geological conditions in this region significantly control the socio-environmental problems of the city and province. Therefore, rigorous geological assessment should be included in any development program for the city and province. Public education related to geological phenomena controlling the safety of city and province environment is also important to be implemented, in order to minimize the occurrence of geo-hazards and eco-geological problems.

Résumé: La ville de Yogyakarta, le capital de la province spéciale de Yogyakarta, est située à la partie méridionale de l'île volcanique d'arc de Java. La géologie de la ville et de la province est commandée par des phénomènes tectoniques de plat actif tels que le volcan actif et la subduction active du plat océanique de l'Indo-Australie au-dessous du plat continental de euro-asian. La ville et la province sont en conséquence enclines aux geohazards (éboulements, inondations, éruption volcanique et tremblements de terre) aussi bien que des problèmes eco-géologiques. En effet, les conditions géologiques dans cette région commandent de manière significative les problèmes socio-environnementaux de la ville et de la province. Par conséquent, l'évaluation géologique rigoureuse devrait être incluse dans n'importe quel programme de développement pour la ville et la province. L'éducation publique liée aux phénomènes géologiques commandant la sûreté de l'environnement de ville et de province est également importante pour être mise en application, afin de réduire au minimum l'occurrence des geo-risques et des problèmes eco-géologiques.

Keywords: volcanic arc island, geohazards and eco-geological problems, public education.

JAVA AS PART OF A VOLCANIC ARC

Yogyakarta city is the capital of Yogyakarta Special Province, situated in Central Java, Indonesia. The city is located only about 30 km from the Merapi Volcano, and about 40 km from the coast of the Indian Ocean. The peak of the volcano reaches the elevation of 2911 m above sea level; it is the most active volcano in Indonesia. The existence of Merapi volcano and the Indian Ocean control the geodynamical processes at Yogyakarta city and province.

The city and the province are considered as a system where the geological phenomena distinctively dominate all the natural processes. Continued subduction of the Indo-Australia Oceanic Plate from the South in the direction below the Eurasia Continental Plate not only resulted in the formation of the active Merapi volcano, but also brought about the formation of mountainous morphology of volcanic and carbonate rocks.

Yogyakarta city is situated at the centre of the province, in the middle part of Yogyakarta valley, which is extending from the north to the south. This valley was actually a graben which was filled by Merapi laharic flows. To the west, a dome of andesitic breccia and lava flows with the intensive fault formation occurred. Meanwhile at the eastern part of the province, steep mountains of carbonaceous-volcanic rocks as well as limestone with karst landscape are exposed. Physiographical and geological conditions of the province and the city are illustrated in Figure 1 and Figure 2.

Apparently, geological conditions in the city and province give rise to the specific georesources and geo-hazards phenomena that significantly control the life and environment in the province and city. Benefits obtained from the geo-resources and the threats due to geo-hazards are the main concern discussed in this paper as addressed below.

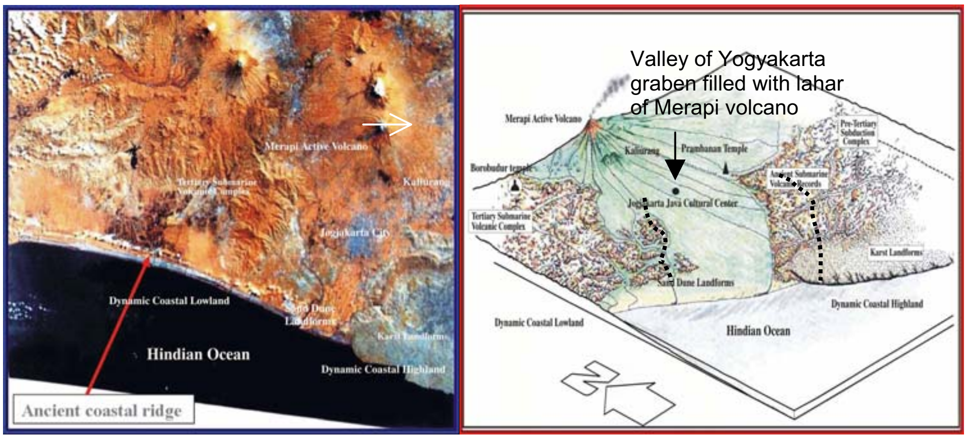

Figure 1. Landsat Image and physiographical conditions of Yogyakarta city and sourrounds (dotted lines indicate the normal faults forming Yogyakarta Graben at the middle of the region).

GEORESOURCES

All products of geological processes used to fulfill human needs are considered as georesouces. Due to the unique characteristics of geological conditions which are dominantly controlled by the volcanic products, good quality and abundance of resources such as fertile soils, valuable minerals, and groundwater, are available in the city and province.

Most of the province is covered by the soil weathered from volcanic ash and provides high fertility for agriculture. The data recorded by Department of Agriculture at Yogyakarta Province from 1999 to 2003 indicate quite significant increments of agricultural productivity (Anon. 2003). The productivity increases from 45,510 kg/ha in 1999 to 49,910 kg/ha in 2003 for paddy, from 23,840 kg/ha in 1999 to 31,370 kg/ha in 2003 for corn, from 65,000 kg/ha to 90,000 kg/ha for horticulture, 10 kg/ha to 20 kg/ha for pineapple and 80 kg/ha to 200 kg/ha for *salak (*the snake-skin like fruit*)*.

Groundwater is the main water resource used for domestic, agricultural and industrial needs in the city and province. The existence of impermeable volcanic clay lenses within the porous sandy tuff that filled the valley of Yogyakarta graben, provides a good groundwater aquifer for the city as well as for Sleman District and Bantul District which are situated at the north and the south of the province. Putra (2003) analyzed that the recharge into groundwater was about 437 x 10^6 m^3/year with the total discharge through the aquifer was 579 x 10^3 m^3/day. However, considering the sustainability of groundwater only about 42 x 10^3 m^3/day groundwater was allowable to be exploited. The model of the aquifer in the valley of Yogyakarta graben is illustrated in Figure 3. The aquifer thickness reaches 100 m underneath the city.

The historical record shows that the development of civilization in this city and province were strongly controlled by the fertility of Yogyakarta region. Some evidence such as temples, artifacts, and manuscripts showed that soil fertility and high water resources were the most important resources supporting the development in this agricultural city. This may also be the reason why many symbols of the glory from the past civilization, such as temples (Figure 4) and one ancient palace built in AD 700-800, are found in the city and surroundings.

Apart from soil and water resources which are important to support agricultural productivity, the province is also considered as a potential area for mineral resources. Abundance of laharic deposits consisting of sand, gravels and boulders occurs in Boyong River flowing from the upper slope part of Merapi Volcanic, and these deposits highly contribute to the supply of building materials. Indeed, the boulders of andesite, which were transported down from the Merapi volcano slope through the rivers, were used as building materials for all of the temples. Formations of limestone and pumaceous breccia, found at the southeast of the city, are also utilized as building and industrial materials. Moreover, some traces of quite highly potential iron sand are also found on the South coast. Meanwhile at the low land, plenty of clay weathered form volcanic ash occurs and is exploited for industrial and building materials.

ECO-GEOLOGICAL PROBLEMS

Based on the population census conducted in the year 2000, the population of the province and the city has reached the numbers of 3,120,500 and 396,700 respectively, with the growth rate of 0.72 % at the province and -0.39 % at the city. Population density at the same year was 979.5/ km^2 in the province and was 12,206.5/ km^2 at the city (www.pemda-diy.go.id). Apparently, the geological characteristics and the high population of the city and province cause quite serious problems of geo-hazards and environmental degradations.

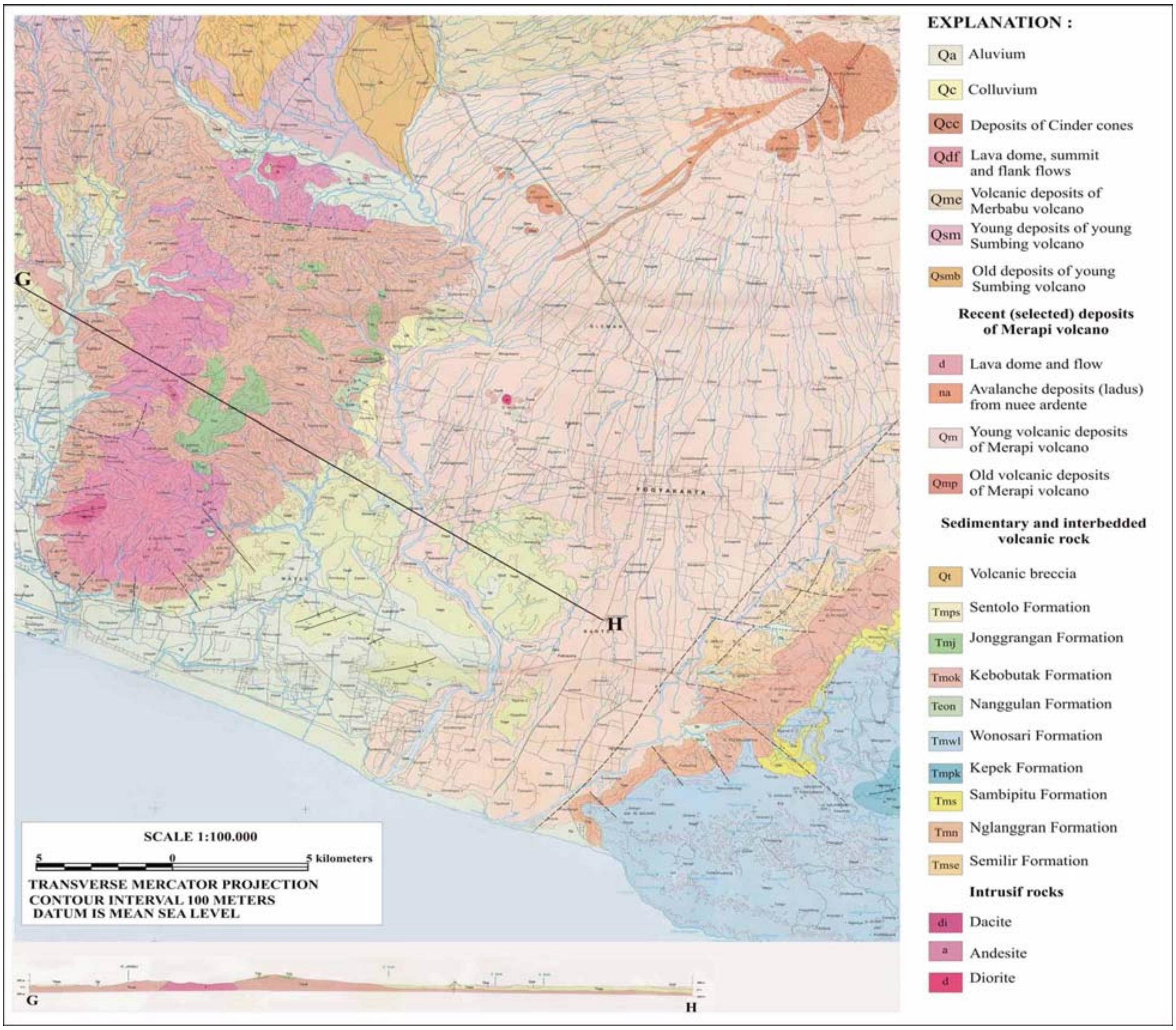

Figure 2. Geology of Yogyakarta and surroundings (Rahardjo et al. 1995)

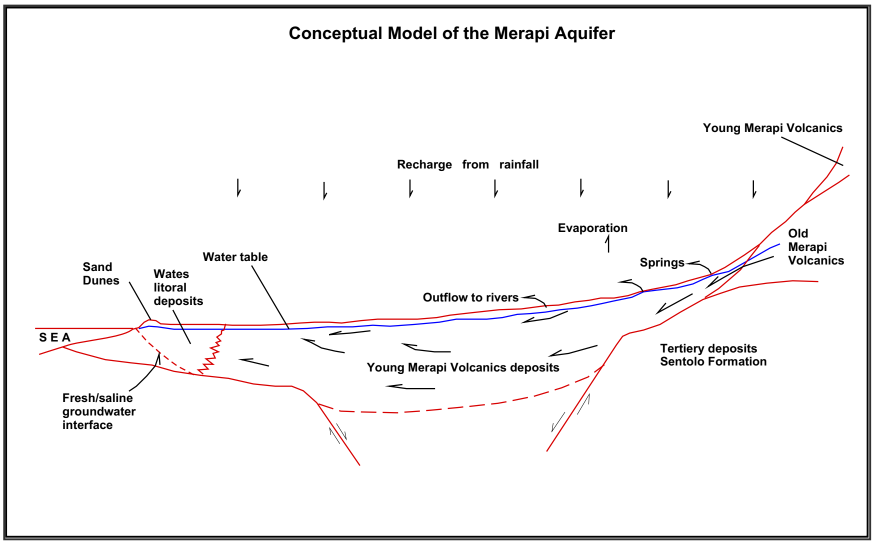

Figure 3. Conceptual model of the Merapi Aquifer (Sir MacDonald & Partners et al. 1984, modified by Putra 2003)

Figure 4. Prambanan temple, symbol of the glory and wealth of the past civilization in 700 AD

Geo-hazards

Geo-hazards, such as landslides, floods, volcanic eruption, earthquake, and tsunamis, are the geological processes which threaten human life due to its potential negative impact to destroy the structures and be harmful for people. Types and distributions of geo-hazards in the province are illustrated in Figure 5. Landslides and floods are considered as the most frequent geohazard.

Landslides occur at the mountainous region at the north, the west and the east parts of the province, mostly induced by the rainfall or river erosion and are controlled by the combined conditions of morphology, slope stratigraphy, geological structures and land use changes. At the West, in Kulon Progo Dome, the steep fractured slope (being steeper than 30^o) of andesitic breccias with the weathered matrix of tuff and some intercalation of tuff layers are the most susceptible slope stratigraphy for landslides. Nine people were killed due to the landslides with rapid movement which occurred on the slopes of the dome in 2001. Meanwhile, at the foot of the dome, slow mass movements (creeps) of colluvial deposits occur and result in some damages on bridges, irrigation channels, roads and houses. The cost for repair and maintenance of this channel has exceeded 1 billion rupiahs every year since the year of 2000. Some rockslides and rock falls also occur in the limestone mining area in the south-east part of the province. At least two people were killed due to this rock slides and falls.

Almost every rainy season flood occurs in the lowland at the city as well as at the South and South-West of the province. Sandy soil deposits from Merapi volcano, which have high water permeability and infiltration rate, cover most part of the city and the middle part of the province. However, the pavements and building settlements at the city prevent the water infiltration and thus result in floods in the rainy season. That is why infiltration wells are installed in order to reduce the flood problems in the city.

Development of settlements in the city has not yet considered the limitation of geological condition. Some new housing and infrastructure are built in the high geological risk zone, such as inside the river valley or on the steep slope, without sufficient countermeasures for floods and landslides. Therefore, some accidents occur in the rainy season due to floods and landslides. In fact, geohazard risk has not yed been considered in the process of releasing permits for development of any new area.

Meanwhile, volcanic eruption periodically occurs about every 4 to 6 years and is considered as the second frequent geohazard. The worst volcanic disaster was in 1994 where glowing avalanches from Merapi burnt the village and hundreds of people in Turgo located at the South West slope of the volcano. This disaster occurred although continued monitoring was conducted in several observatories located at the slopes of Merapi volcano. Laharic flows from Merapi also become a common threat for the people living nearby the rivers flowing from the volcano. Some Sabo Dams had been built to control the over flow of the lahars.

The Indonesian Meteorological and Geophysical Agency recorded earthquakes in Yogyakarta in the years 1867, 1939, 1943, 1976, 2001 (2 times) and 2004 (10 times) with various magnitudes of 3.8 to 5.3 Richter.

However, on 27 May 2006 an earthquake of 6.2 Moment Magnitude struck the southern part of the Province with its epicenter at UTC 8.007 S and 110.286 E. It caused more than 5000 deaths and about 100,000 houses were damaged or collapsed. Then, on 18th July 2006 the southern coast was struck by a tsunami with a maximum wave of 2 m height due to an oceanic earthquake which occurred in Indian Ocean at UTC 9.23 S and 107.33 E.

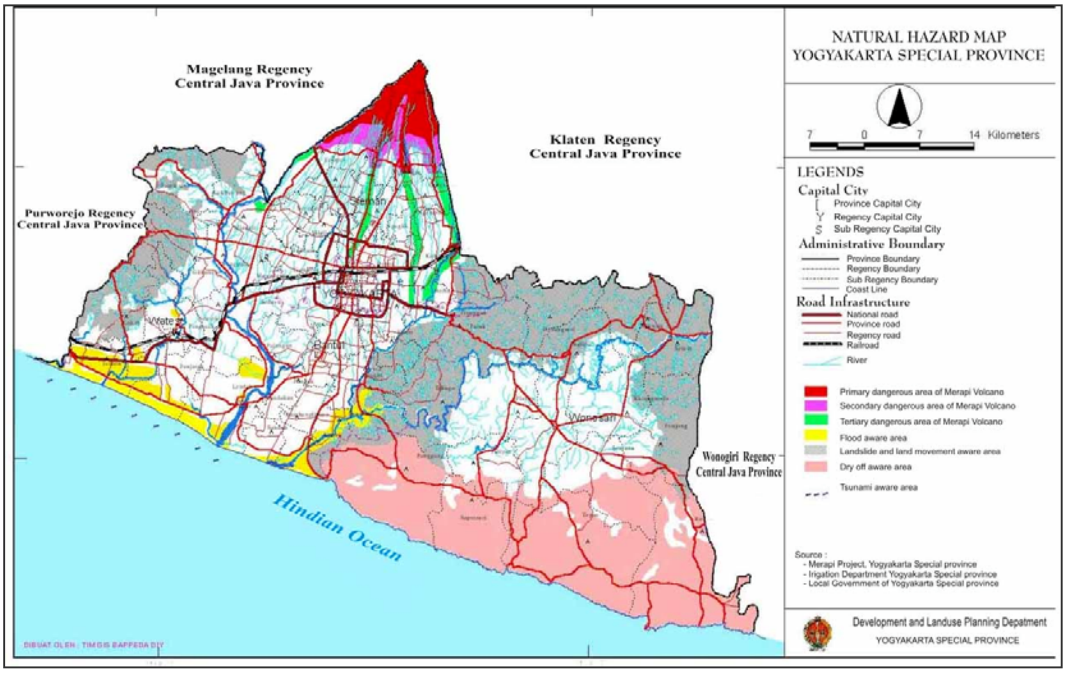

Figure 5. Types and distributions of geo-hazards in the province (Anon. 2000).

Environmental degradation

Degradation of land resources and groundwater resources are considered as the prominent environmental degradations. Uncontrolled exploitations of sands and stones as well as groundwater inevitably occur and gradually will result in land and water degradations.

The exploitation of sands and stones

The exploitation of sands and stones is a very complicated problem at the lower and the foot slope of Merapi Volcano. Such exploitation results in both benefits and disaster. Within several parts of the volcano slopes, those activities have been causing the destruction of the landscape, especially slope failures on cliffs and back-hills, where the cliff and hills are actually a good protection to resist flood and lava-flows. The forest and the environment become destroyed; the drawdown of average water level occurs; some springs are dry, and roads, bridges and dams become damaged.

The other negative impact of this sand and stone exploitations would be socio-environmental problems, such as noise, pollution dust, infection of the human eyes, breathing problems and work accidents. In comparison to the adjacent Province, i.e. Magelang Regency which has similar geological and socio-economical conditions, in 2002 the social cost of these socio-environmental problems due to uncontrolled sand and stone exploitation had reached Rp. 23.776.000.000, - each year since the year of 1998 to 2000. While the benefits that could be earned from these exploitations was about Rp. 43.506.000.000, - each year. The regency income had increased from Rp. 236.000.000, - each year (in 1997/1998) into Rp. 2.218.000.000, - each year. However, that would not count with the physical and environmental damage and the profits for the investor.

Obviously, the mining activities and development of settlements bring about a reduction of rice field areas. The rice field around the areas within the year of 1996-2000 is reducing significantly as illustrated in Table 1, Table 2

Table 1. Presentation of rice field with total field in Regency & city (hectares) (ANON 2003)

Area	Type	1996	1997	1998	1999	2000
Sleman	Regency	43	42	42	42	41
Bantul	Regency	33	33	33	33	32
Yogya	Town	6	6	5	5	5
Magelang	Town	16	15	15	15	15

This trend of rice field area reduction seems to be increasing and continuing. It is crucial that the reduction of rice field seems to be correlated with the development of industrialization and settlement areas, instead of being due to the population growth.

Table2. Rice field reduction (hectares) (ANON 2003)

Area	Type	1996-1997	1997-1998	1998-1999	1999-2000
Sleman	Regency	0.83	0.25	0.12	3.33
Bantul	Regency	0.64	0.31	0.22	0.72
Yogya	Town	5.64	2.79	7.82	6.06
Magelang	Town	1.41	1.45	1.45	1.48

Water problems

Most of the water supply in the city and province is provided from groundwater through shallow wells utilization. Problem of continued lowering of the groundwater table occurs due to the development of industry and hotels which tend to install deep wells. The draw-down of free-water-level (unconfined aquifer) is truly variable in some areas. The estimated number is about 10 cm each year. It requires a systematical-observation-well to make sure of the problem.

The most crucial problem would be subsurface water quality. The water in some settlement areas has been contaminated by the bacteria of Entamuba-Coli, Iron, Magnesium, Detergents, etc. The contamination of E-Coli bacteria has already exceeded 3600/100 ml in some settlement areas in the city such as Terban, Ledok Ratmakan, and Kraton sultan's Palace. Meanwhile, the BOD, detergent, and nitrate content also has been over the recommended limit (Anon 1997). In Bantul Regency, even if the water is still considered as fresh water, in somer places it brings Fe and Mn above the recommended limit, so does it with the E-Coli bacteria (Putra 2003).

Coastal region problem

The sand dunes ecosystem at Parangtritis has 190 units, as barchans, longitudinal, parabolic and comb types. The types of sand dunes are controlled by deferent factors: (1) periodically added total sand sediment, (2) continuous sea current, (3) sun intensity, (4) continuous wind, (5) natural walls, (6) vegetation, and (7) culture.

Now, the sand dunes area shows serious degradation. The degradation caused by internal and external pressure factors as the agriculture for livelihood of the growing community, also the partial regulation on growth in an autonomy era. The roots of the problems are missing strategies and practices for the management applied in sand dune areas, which is not based on knowledge on sand dunes and coastal management.

The degree of degradation will be reduced if all stakeholders transform the strategies and practices of karsts management; agree to apply karsts ecosystem and water conservation management, also based on social, biotic and physical function.

DISCUSSION

In order to further develop the city and province, the geological conditions obviously will cause limitations. The mountainous land at the East and the West tend to be a restriction for developing the transportation access towards the other cities and provinces, and this affects the economical development of Yogyakarta city and province. Therefore in the year 2007 the Government at the Province level plans to build a tunnel passing through the mountains at the east part of Yogyakarta. However, detailed engineering geological investigation is required because some major faults occur and some discontinuities (cracks) exist within the rock mass. Indeed, rock mass quality assessment and stability analyses are necessary to prevent the failure of tunnel construction. Environmental Impact Assessment also will have to be carried out to minimize the potential negative impact of tunnel construction.

Obviously, rigorous geological assessment should be considered in any development plan. The evidence has shown that poor consideration of geological conditions in the past development program of the city and province results in problems of geohazard and environmental degradation. The importance to understand geological conditions controlling the safety of development areas should also disseminated through the public. Public education related to geological phenomena controlling environmental safety should also be established. Through such education, the influence of human activities to induce any hazard can be minimized. As well, the understanding, awareness and readiness of the public to anticipate geo-hazards can be improved. Integration of traditional wisdom in this public education is necessary to support the effectiveness of the education program. Indeed, the establishment of early warning system in the vulnerable area may not be appropriate without the implementation of public education.

CONCLUSION

Geological conditions in Yogyakarta city and province significantly control the socio-environmental problem in the city and province. Therefore, rigorous geological assessment should be included in any development program of the city and province. Public education related to geological phenomena controlling the safety of city and province environment is also important to be implemented, in order to minimize the occurrence of geohazard and eco-geological problems.

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REFERENCE

ANON. 1997. Natural resources Map of Yogyakarta Special Province, Development and Landuse Planning Department, Yogyakarta Special Province.

ANON. 2000. Natural Hazard Map of Yogyakarta Special Province, Development and Land Use Planning Department, Yogyakarta Special Province.

ANON. 2003. BPS - Statistics of Daerah Istimewa Yogyakarta Province, http://www.bps.go.id/profile/diy.shtml

MACDONALD & PARTNERS, BINNIE & PARTNERS, HUNTING TECHNICAL SERVICES LTD. 1984. Greater Yogyakarta Groundwater Resources Study, Volume 13, Album of Map and Drawing

PUTRA, D.P.E. 2003. Integrated Water Resources Managament in Merapi – Yogyakarta Basin, Faculty of Engineering Gadjah Mada University and AUNSeed – JICA Project, Unpublished
RAHARDJO, W., SUKANDARRUMIDI & ROSIDI, H.M.D. 1995. Peta Geologi Lembar Yogyakarta, Jawa (Yogyakarta Quadrangle Geological Map), Pusat Penelitian dan Pengembangan Geologi, Bandung.