Nature-based solutions for integrating flood and land subsidence: A case study in Jakarta and Semarang

I B Pramono

1 Watershed Management Technology Center, Ministry of Environment and Forestry, Jl. Jend. A. Yani Pabelan-Kartasura, Central Java, Indonesia

Abstract. Floods in Jakarta and Semarang are more frequent and impact more expansive areas. So far, flood management has been done mainly by increasing the capacity of drainage channels and draining water into the sea more quickly. This flood management needs to be evaluated because it leads land subsidence in Jakarta and Semarang to deepen. Thus, this research aims to identify the extent to which land subsidence causes the expansion of floods and alternative solutions to deal with floods and land subsidence in an integrative manner, especially in Ciliwung (Jakarta) and Garang (Semarang) watersheds. The method used was a review of various publications concerning findings of land subsidence, flooding, and the experiences of several countries in dealing with these problems. The results showed that land subsidence has occurred in Jakarta and Semarang. As a result of land subsidence, the flooding areas have increased due to the increase in lowlands, and therefore, it is difficult for the existing water to flow into the sea. Handling floods and land subsidence cannot be conducted locally but must be carried out in an integrative manner with a watershed and groundwater basin approach. One of the causes of land subsidence is excessive groundwater extraction. On the other hand, the groundwater must be increased. The increase in groundwater supplies not only reduces land subsidence but also reduces flooding, seawater intrusion and prevents drought in the dry season. A nature-based solution for reducing flood and land subsidence can be achieved by increasing vegetation cover and constructing water conservation buildings in the upstream areas.

1. Introduction

Floods and land subsidence are often handled separately. Flood handling by accelerating flood flow into the sea will reduce water entering the soil and potentially decrease groundwater during the dry season. The extensive groundwater extraction not only leads to decreased groundwater supply but also causes land subsidence. As a result of this subsidence, the flood area has become more widespread.

In Jakarta, land subsidence varies from one place to the others. In 2016, land subsidence in West Jakarta, Central Jakarta, North Jakarta, East Jakarta, and South Jakarta amounted to -11.7; -13.1; -13.0; -12.1; -13.2 cm/year, respectively [1]. Meanwhile, land subsidence in North and East Semarang varies from 9-13 cm/year, 6-9 cm/year in West Semarang, and 3-6 cm/year in South Semarang [2]. Besides, land subsidence in Jakarta fluctuates every year, but there is a tendency to increase every year [1]. A recent study’s results showed that land subsidence in Jakarta was about 6 cm/year, while in Semarang, it was 10 cm/year [3].
Moreover, the development of Jakarta and Semarang cities has made the increase in a clean water crisis. The source of clean water from the State Drinking Water Company (PAM) cannot meet the needs of clean water for the Jakarta residents because the clean water consumption is greater than the clean water availability from PAM [4]. The need for clean water in Jakarta is 413 million m$^3$/year, while the supply from the PAM is only 200 million m$^3$/year [5]. A deficit of 213 million m$^2$ is expected from groundwater. Besides, Semarang city also faces the problem of lack of clean water. The PAM of Semarang city can only meet 25% of the clean water for the residents [6]. Therefore, the rest of the residents use groundwater as a source of clean water.

The problem of lack of clean water is worsened by the trend of climate change. There is a tendency for the amount of rainwater to be the same. However, the rainfall intensity increases, and the duration of rainfall becomes shorter. Consequently, the ability of soil to absorb rainfall decreases. This condition is exacerbated by the increase in the built-up zone; hence, most rainwater directly becomes surface runoff, which contributes to flooding. For example, settlements in the Ciliwung watershed (Jakarta) are already 51% of the watershed area [7]; meanwhile, settlements in the Garang watershed (Semarang) had increased by 978 hectares from 2013 to 2018 [8]. In order to manage the flooding in Jakarta and Semarang, water drainage canals have been built into the sea, namely the west flood canal and the east flood canal. The canal construction is expected to reduce flooding in Jakarta and Semarang. However, because the area experiencing land subsidence is broader and more profound, floods still occur, and the inundated area is wider. As a result, less rainwater enters the soil, and the groundwater supplies decrease.

To handle flooding and land subsidence, an integrated approach should be applied. This method is a nature-based solution (NBS), which is entering as much rainwater as possible into the soil to reduce flooding, increasing groundwater supply, reducing land subsidence and seawater intrusion. The NBS can be interpreted as an ecosystem solution, providing benefits for the environment, society, and economy [9]. Furthermore, flood mitigation in urban areas can be carried out by restoring hydrological functions through NBS [10]. The NBS has the advantage of increasing the storage capacity of the drainage system by increasing infiltration and water retention capacity and reducing peak flow [11].

Considering that flooding in Jakarta and Semarang is becoming more frequent and widespread, it is necessary to implement NBS in these cities. The NBS method is expected to reduce floods, increase groundwater recharge, reduce land subsidence, and decrease seawater intrusion.

2. Methods
Literature study of floods and land subsidence in Jakarta and Semarang was undertaken through the peer-reviewed journal and other information. In addition, a literature review was also conducted for the methods in reducing flooding by entering rainwater into soil that has been applied by several countries and has potential for Jakarta and Semarang.

3. Results and discussion
3.1. Land cover change in Jakarta and Semarang
Population growth in Jakarta and Semarang has led to changes in land cover from agricultural land to residential and industrial areas. Land cover change in Jakarta is represented by the Ciliwung watershed, while in Semarang, it is represented by the Garang watershed.

3.1.1. Land cover change in Jakarta (Ciliwung watershed). Land cover in Jakarta changes very rapidly as the population increases. The growth of settlements in Jakarta and upstream areas, such as Depok and Bogor, are high-speed. Figure 1 shows the population growth from 1983 to 2002. In 1983, the land cover was still dominated by agricultural land, but more than 50% of the land cover was settlements in 2002. As a result, the ability of the land to absorb rainwater is reduced, and therefore, some of the rainwater becomes surface runoff and causes flooding in downstream areas.
3.1.2. Land cover change in Semarang (Garang watershed). One of the watersheds that enter Semarang city is the Garang watershed. The changes in land cover in the Garang watershed are also speedy. Figure 2 displays that in 1994, the settlement area was still small, especially in the middle and upstream parts of the watershed. However, from 2001, the residential areas had begun to develop in the middle and upstream areas. In 2008, residential areas expanded to the downstream, middle, and upstream of the watershed. Consequently, the ability of the Garang watershed to absorb rainwater has decreased, and floods in Semarang city have become more widespread and frequent.

3.2. Land subsidence and flood in Jakarta and Semarang

3.2.1. Land subsidence and flood areas in Jakarta. There is a strong relationship between land subsidence and flood area in Jakarta. Land subsidence in Jakarta occurs not only in the coastal but also in inland areas. These areas experienced more severe flooding, as shown in Figure 3. In addition, subsidence along the river also exacerbated the occurrence of flooding. It also caused the drainage system to malfunction [14].

Figure 1. Land cover map of Jakarta from 1983 to 2002 [12]

Figure 2. Land cover map of Garang watershed from 1994 to 2008 [13]

Figure 3. Land cover map of Jakarta showing the land subsidence and flood areas [14].
Figure 3. Spatial correlation between land subsidence and flooding area in Jakarta [14]
Note: Subsidence rate from high to low (from red to blue)

3.2.2. Land subsidence and flooding areas in Semarang. Land subsidence occurs in the north and northeast of Semarang city [2]. The highest flood threat level also occurs in the north and northeast of Semarang city [15], as presented in Figure 4. Therefore, there is a strong relationship between land subsidence and flooding in Semarang.

Figure 4. Spatial correlation between land subsidence and flooding area in Semarang [2] and [15]
Note: Legenda = Legend; Penurunan Muka Tanah = Land Subsidence
Rendah = Low (green); Sedang = Moderate (yellow); Tinggi = High (red)

3.3. Nature-based solutions
Handling floods and land subsidence must be in an integrative manner conducted naturally, namely incorporating water into the soil at every place or land cover. In this regard, surface water that causes flooding is reduced. On the other hand, groundwater supplies are increased. This available groundwater can be used in the dry season. In addition, water conservation activities will also reduce land subsidence and seawater intrusion in downstream areas. Therefore, the natural way of incorporating water into the soil can solve four problems at once: reducing flood, increasing groundwater availability, reducing land subsidence, and reducing seawater intrusions. In the sub-
section 3.3.1, several techniques of water conservation are presented in forest areas, agricultural land, settlements, parking areas, and riverside.

3.3.1. Water conservation at forest and estate. Forest land cover has limitations in absorbing water. The research results in pine forests in Gombong showed that the function of pine forests in absorbing water was only at low and moderate rainfall intensity (less than 70 mm/event) [16]. To increase the absorption of rainwater at the forest floor, it is necessary to apply water conservation techniques in the forest, such as "Rorak" (water trap), as presented in Figure 5.

![Figure 5. Water trap in the pine forest at Tawangmangu, Central Java.](image)

3.3.2. Water conservation on agricultural land. Ponds or reservoirs in agricultural land have many functions, such as increasing water infiltration irrigation for surrounding areas, and they can be used for fish cultivation, as illustrated in Figure 6.

![Figure 6. Water conservation in agricultural land [17]](image)

3.3.3. Water conservation in residential areas. Settlements in Jakarta and Semarang are growing very fast. Therefore, the built-up or impermeable areas are getting wider. As a result, much rainwater becomes surface runoff. Increasing water infiltration in residential areas can be done by making infiltration wells, as shown in Figure 7. This infiltration well can reduce flooding in Jakarta by up to 30% [18].
Figure 7. Infiltration well in residence area [19]

Besides making infiltration wells individually, it is necessary to add communal infiltration wells. If possible, it is better if the rainwater falling inside the residential complex is absorbed into the soil and becomes zero runoff.

3.3.4. Water conservation at the road and parking area. Water conservation on either side of the road and parking area has not been widely applied. Meanwhile, the potential for surface runoff at that location is tremendous because the land cover has a runoff coefficient of 1, or all of the rainwater becomes surface runoff. An example of water conservation in a parking area is illustrated in Figure 8.

Figure 8. Water conservation in parking area [20]

3.3.5. Water conservation at the riverside. The concept of river management in Indonesia is still oriented towards removing water as quickly as possible downstream. As a result, downstream flooding will worsen because runoff cannot infiltrate the riparian effectively [21]. Thus, riverside management is crucial to reduce flooding in downstream areas. The implementation of riverside management has begun in the Netherlands, known as Room for River, and the concept of riverside management is being offered in the Ciliwung watershed, Jakarta.

Room for the river has been developed by the Dutch government since 1996 [22]. Developing room for the river aims to overcome flooding. Room for the river is an integrated watershed management method through integrated water resources management. Figure 9 is a schematic illustration of the room for the river.
In addition, the water retention at the riverside is not only used to reduce flooding downstream but also can be used for other purposes. In the middle part of the Ciliwung watershed, the function of water resource management is directed as a water reservoir by making a pond on the edge of the outer curve of the river. Mini ponds can accommodate excess water during the rainy season and can be used for fishing and recreation, as shown in the schema in Figure 10 [21].

The implementation of room for river and water retention is expected to increase water infiltration into the ground so that it will reduce flooding and, at the same time, increase the supply of groundwater, which will reduce land subsidence and seawater intrusion.

3.3.6. Management of groundwater utility. The experience of several countries, such as Japan and China, revealed that groundwater extraction restrictions could reduce land subsidence. The highest land subsidence in Tokyo ever reached 24 cm/year in 1968. At that time, groundwater abstraction reached 1.5 million cubic meters per day. After setting up groundwater extraction, land subsidence decreased drastically; the decrease was not more than 2 cm/year. Even in the last five years, the decrease was only about 1 cm/year. Approximately 550,000 m$^3$ of groundwater is still pumped daily to meet the population's daily needs and other uses [24]. The increase of land subsidence in Tokyo can be prevented by strictly apply groundwater extraction regulations. Pumping regulations in Tokyo include the Environmental Preservation Ordinance, Industrial Water Law, and Building Water Low [24].

Meanwhile, in Shanghai, China, the land subsidence in 2001 reached 12 mm/year, but after implementing the 2006 regulation, it decreased to 9 mm/year, and it became 6 mm/year after implementing the 2013 regulation [25]. It is due to a decrease in groundwater extraction from 8...
million m³/year in 2001 to 1 million m³/year in 2013, accompanied by additional groundwater recharge, as shown in Figure 11 below.

**Figure 11.** The volume of groundwater withdrawal and recharge from Shanghai from 2000 to 2017 [25]

4. Conclusion

Flood management and land subsidence cannot be separated. Flood management and land subsidence must be integrated because flood management by flowing water into the sea as quickly as possible will cause decreasing water infiltration into the soil while groundwater extraction increases. As a result, the ground level drops, and the area inundated by floods increases. Besides, a paradigm in managing floods should be shifted from draining rainwater to absorbing rainwater. Since changes in land cover from agriculture to settlements and industries are unavoidable, water conservation should be intensified. The regulation of groundwater utilization also needs to be tightened to reduce land subsidence, seawater intrusion, and flooding. Returning to nature is the most appropriate solution for flood and land subsidence.

References

[1] Cyntia C and Pudja I P 2018 Subsidence analysis in DKI Jakarta using Differential Interferometry Synthetic Aperture Radar (DInSAR) Method Sustinere J. Environ. Sustain. 2 118–27

[2] Yuwono B D, Abidin H Z and Hilmi M 2013 Analisa geospasial penyebab penurunan muka tanah di Kota Semarang Prosiding SNST Fakultas Teknik vol 1 (Semarang: Universitas Wahid Hasyim) pp 1–8

[3] Bott L M, Schöne T, Illigner J, Haghshenas Haghhighi M, Gisevius K and Braun B 2021 Land subsidence in Jakarta and Semarang Bay – The relationship between physical processes, risk perception, and household adaptation Ocean Coast. Manag. 211 105775

[4] Kuncahyo B, Firdaus I, Mujahidah S Z, Arya M G, Azhar and Amari D 2013 Prediksi kelangkaan air bersih PDAM di Jakarta menggunakan pemodelan sistem

[5] Kumar P, Masago Y, Mishra B K, Jalilov S, Emam A R, Kefi M and Fujushi K 2017 Current assessment and future outlook for water resources considering climate change and a population burst: A case study of Ciliwung River, Jakarta City, Indonesia Water 9 410

[6] Mukaromah H 2020 Rainwater harvesting as an alternative water source in Semarang, Indonesia: The problems and benefits IOP Conference Series: Earth and Environmental Science vol 447 (IOP Publishing) p 012059.

[7] Pramono I B, Savitri E, Donie S, Basuki T M, Supangat A B, Cahiyo S A and Putra R B W M 2015 Restorasi DAS Ciliwung
[8] Pane F M R, Suprayogi A and Sabri L 2018 Analisis pengaruh perubahan tutupan lahan Daerah Aliran Sungai tahun 2013 dan 2018 terhadap peningkatan debit puncak Sungai Kaligarang J. Geod. Undip 9 285–94
[9] Maes J and Jacobs S 2017 Nature-Based Solutions for Europe’s Sustainable Development Conserv. Lett. 10 121–4
[10] Costa S, Peters R, Martins R, Postmes L, Keizer J J and Roebeling P 2021 Effectiveness of nature-based solutions on pluvial flood hazard mitigation: The case study of the city of Eindhoven (the Netherlands) Resources 10 24
[11] Fiori A and Volpi E 2020 On the Effectiveness of LID infrastructures for the attenuation of urban flooding at the catchment scale Water Resources. Res. 56 1–21
[12] Moe I R, Kure S, Januriyadi N F, Farid M, Udo K, Kazama S and Koshimura S 2017 Future projection of flood inundation considering land-use changes and land subsidence in Jakarta, Indonesia Hydrol. Res. Lett. 11 99–105
[13] Cahyadi A, Nugraha H, Nurjani E, Yananto A and Wijaya M S 2012 Using remote sensing multi-temporal image to analyse the land use changes and its impact on the peak discharge in Garang Watershed Central Java J. Mat. Sains dan Teknol. 13 73–9
[14] Abidin H Z, Andreas H, Gumilar I and Wibowo I R R 2015 On correlation between urban development, land subsidence and flooding phenomena in Jakarta IAHS-AISH Proceedings and Reports vol 370 (Copernicus GmbH) pp 15–20
[15] Pratiwi R D and Nugraha A L 2016 Pemetaan multi bencana Kota Semarang J. Geod. Undip 5 122–31
[16] Pramono I B, Gunawan T and Budiastuti M T S 2016 The ability of pine forests in reducing peak flow at Kedungbulus sub watershed, Central Java, Indonesia Int J Appl Env. Sci. 11 1549–68
[17] Subagyono K and Pawitan H 2008 Water harvesting techniques for sustainable water resources management in catchments area Bull. TERC, Univ. Tsukuba pp 18–30
[18] Pramono I B, Savitri E, Donie S, Basuki T M, Supangat A B, Cahyono S A and Putra R B W M 2015 Restorasi DAS Ciliwung (UNS Press)
[19] Belladona M, Nasir N and Agustomi E 2018 Design of Infiltration Well to Reduce Inundation in Rawa Makmur Village, Bengkulu City J. Appl. Sci. Adv. Technol.1 53–8
[20] Shafique M, Kim R and Kyung-Ho K 2018 Evaluating the Capability of Grass Swale for the Rainfall Runoff Reduction from an Urban Parking Lot, Seoul, Korea Int. J. Environ. Res. Public Heal. 15 537
[21] Noviandi T U Z, Kaswanto R L and Arifin H S 2017 Riparian landscape management in the midstream of Ciliwung River as supporting Water Sensitive Cities program with priority of productive landscape IOP Conference Series: Earth and Environmental Science vol 91 (IOP Publishing) p 012033
[22] Rijke J, Herk S van, Zevenbergen C and Ashley R 2012 Room for the river: Delivering integrated river basin management in the Netherlands Int. J. River Basin Manag. 10 369–82
[23] Zevenbergen C, Rijke J, Van Herk S, Ludy J and Ashley R Room for the river: International relevance
[24] Sato C, Haga M and Nishino J 2006 International review for environmental strategies special feature on groundwater management and policy land subsidence and groundwater management in Tokyo Int. Rev. Environ. Strateg. 6 403–24
[25] He X-C, Yang T-L, Shen S-L, Xu Y-S and Arulrajah A 2019 Land subsidence control zone and policy for the environmental protection of Shanghai Int. J. Environ. Res. Public Heal. 16 2729