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A predictive model to assess spatial planning in addressing hydro-meteorological hazards: A case study of Semarang City, Indonesia

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Abstract

Global warming has negatively influenced the quality of life of many people, especially those who live in coastal areas. Sea-level-rise in northern Java, Indonesia, has impacted coastal cities prone to flooding and inundation. This study reports the extent to which spatial planning, mandated by the Indonesian Law 26/2007 to minimise the risk of people and improve their resilience, has taken into account hydro-meteorological hazard of Semarang City in northern Java. Geographic Information System (GIS) based spatial analyses were used to predict the anticipated vulnerability of the area based on the combined effect of two processes, namely, a tendency towards land subsidence and an increase in sea level. Further, by overlaying the current and projected vulnerability maps to the year 2031 with the planned land use of the city in the same timeframes, results show that most precincts with anticipated flooding and inundation are residential, industrial, and commercial areas, indicating that the current spatial land use plan has not adequately accounted for the hazard. The methodology employed in this study should prove of use for other cities on the littoral.

Keywords

Spatial planning; Hydro-meteorological hazard; *Rob;* GIS

1. Introduction

Global warming has been an important issue for at least the last three decades. The melting ice in the Arctic has significantly increased the volume of global sea water, prompting sea level rises (SLR) by 0.5–2.3 m at the end of the century [1]. Consequently, inundation in many coastal cities could become more severe in future.

Coastal cities face new or aggravated stresses from climate impacts [2], owing to change in both the marine and the terrestrial environments [3]. Over time, coastal land will be more severely affected by SLR, storm surge and wave height, whereas inland changes include alterations in river flow regimes [4]. About 600 million people and two-third of the world's major cities located in coastal areas have been influenced by SLR [5]

With one of the longest coastlines in the world, the archipelago of Indonesia has many cities located in coastal areas. They link regional trading activities between their hinterland and other cities beyond their island at all scales ranging from local to international. Given rapid growth, their nearby coastal areas have also become attractive places for settlement, fishery and tourism.

Natural disasters frequently occur in Indonesia [6–8]. Given its tropical climate, the nation often faces extreme weather, temperature and wind effects. Such climatic conditions, along with the growth in human activities and environmental degradation, tend to worsen and lead to an increasing incidence and intensity of natural disasters, in particular, hydro-meteorological hazards such as floods, landslides, tropical cyclones/storm and drought. According to Nied et al. [9], the characteristics of floods are affected by hydro-meteorological conditions. The flood types are linked to soil moisture and weather patterns, primarily determined by the season, the presence of snow, and atmospheric conditions in the build-up period. Flooding events also vary among the seasons.

In northern Java's coastal cities, inundation has been worsened by SLR, which causes *Rob,* a local term for this hydro-meteorological hazard. Technically, *Rob* refers to both inundation that permanently occurs and flooding that appears temporarily in an area, both of which are caused by the sea water overflow. In areas being affected by *Rob*, many people live unsafe. The more economically capable inhabitants can often move to safer areas. However, many others decide to stay in place for various reasons, including financial restrictions, the need to be close to workplaces, as well as other historical and cultural influences. Despite their attempts to adapt *in situ*, they are vulnerable to such hazard.

There is extensive literature on the scale of SLR in various locations around the world. Nicholls and Mimura [10], for example, estimated that sea level will increase by 10–25 cm by the end of the 21st century. Huq et al. [11] predicted that the rise would vary from around 18–59 cm depending on location. Overall, sea level could rise by 50 cm [12], with a one percent possibility of 100 cm [10]. In Indonesia, the extent of SLR in the coastal area of Makassar can amounted to 8–10 mm per year according to Hidayat [13]. This estimate concurs with Julzarika [14] which predicts that sea level around Semarang will rise between 50 and 100 cm in the following decade. A more recent study by Ismunarti, Satriadi, and Rifai

[15] show a much large rate of 14.2 mm/year based on data from the Indonesian Agency of Meteorology, Climatology and Geophysics' data (*Badan Meteorologi, Klimatologi dan Geofisika*/BMKG) from 1995 to 2014.

Research on coastal development has featured strongly in the literature, leading to improved understanding of its: impact, risk and vulnerability assessment [3,6,16–20]; management, planning and sustainable adaptation [4,21]; and hazard mitigation planning [22]. Seaboard cities need to pay special attention to community awareness of, and resilience toward, hydro-meteorological hazards, especially around themes of climate change. Human settlement has long been drawn to coasts, which provide many resources and trading opportunities, but also expose residents to various hazards [5]. A wide range of climate change and hazard impacts can afflict metropolitan coastal areas where a dynamic and complex interaction of natural and socioeconomic systems occurs in highly heterogeneous contexts [23]. Adapting to climate change is therefore an essential part of ensuring that cities remain desirable places to live and work.

Spatial planning is a common instruments for disaster risk reduction [4,6,24–28]. Concomitantly, Indonesian Law No. 26/2007 on Spatial Planning determines that disaster mitigation should be part of a spatial land use plan. The Indonesian National Spatial Plan (*Rencana Tata Ruang Wilayah Nasional*) consists of both a Spatial Structure Plan (*Rencana Struktur Ruang*) and Spatial Pattern Plan (*Rencana Pola Ruang*). The Spatial Structure Plan determines the hierarchy of service centres and relationships among different spatial units, while the Spatial Pattern Plan regulates land uses such as conservation, cultivation and built-up areas. In principal, the Spatial Pattern Plan should take into consideration, among other matters, hydro-meteorological hazards, particularly in planning the land use in the coastal regions to reduce negative impacts of disasters before, during, and after their occurrence [11,29,30] and improve local resilience [31]. Spatial planning strategies can vary from avoiding potential direct impacts, relocating vulnerable people to less risky locations, and modifying environmental design, to maintaining good spatial management [32]. However, previous studies show that current local spatial plans in Indonesia have neither considered this factor nor had this factor adequately addressed in practice [33–38]. A study of Maulana and Buchori [36] assessing the current land use of Semarang shows its incompatibility with the Spatial Plan. Therefore, there is a pressing need to understand the extent to which spatial planning in Indonesia has accommodated the potential of hydro-meteorological hazard and how to improve its coverage.

Geographic Information System (GIS) technology has been applied extensively to map and analyse the spatial dimension of hazards. It is increasingly used as a tool to plan for, and generate, land use planning maps [26,39–42]. GIS has been employed in other related fields such as disaster mitigation [23,26,43,44], forest management [45], infrastructure and utility placement [46,47], environmental management [48–50], land use planning [42,51], and coastal management [52]. The development of GIS supported by other geospatial technologies such as surveying and remote sensing offers powerful tools to aid environmental monitoring, mapping, modelling, and management [53].

This study aims to achieve two objectives fundamental to our understanding of current and potential hydro-meteorological hazard of *Rob* in the coastal city of Semarang in northern Java, Indonesia. First, it assesses the vulnerability of the area to *Rob* based on the combined effect of two processes, namely, a tendency towards land subsidence and an increase in sea level, and predicts vulnerability of the area to this hazard to the year 2031. Second, it evaluates the extent to which the Spatial Plan of the city has taken into account this hydro-meteorological hazards resulted from inundation and flooding. The following section introduces the study area, data and methods. This is then followed by results in Section 3, discussion in Section 4, and conclusion in the last section.

2. Study area, data, and methods

2.1. Study area

Semarang City, Indonesia, is selected as the case study site due to its geographical location along the coast as well as its topographical variations, ranging from flat land located in the north coast to hilly areas in the south. The study area is defined along the coast of Semarang City with an elevation of 20 m or less from mean sea level. Some enclaves having contour values over 20 m, including the hilly areas on the south side and Tugu Sub District (*Kecamatan*), are also included. The size of the area is 13,832 ha (Fig. 1).

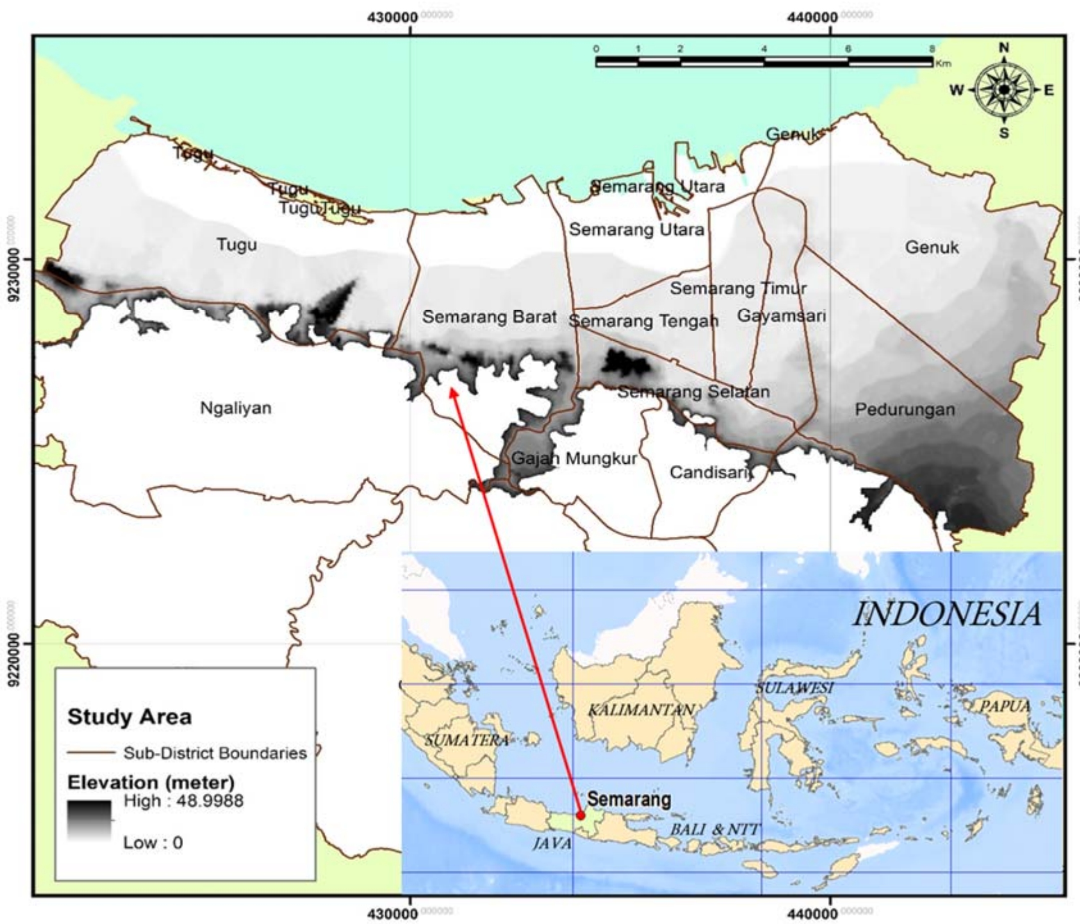

Figure 1 The study area of Semarang in Central Java, Indonesia

Semarang, the capital of Central Java Province, routinely faces environmental problems caused by the rise of sea level. This is worsened by land subsidence occurring in the coastal areas [12,54]. Therefore, *Rob* causes devastating consequences to many residential areas on the northern side of the city throughout the year. Sejati and Buchori [33] classified the vulnerability of areas being affected by *Rob* into three scales – high, moderate, and low – with estimated sizes of 19.1 km^2, 13.7 km^2, and 39.6 km^2, respectively. Most of the areas that are highly vulnerable to *Rob* are residential areas. This situation may become worsen over time when the hazardous areas extends further from the coastal areas to higher altitudes [33]. Furthermore, Marfai and King [12] reveal that 27.5 ha of land in Semarang in 2020 will be situated 1.5–2.0 m below sea level. Their work also shows that 20 urban villages on the coast are most vulnerable to *Rob*[55].

2.2. Data

Both primary and secondary data were used in this research. A topographic map with a two-meter contour interval was obtained from the UDMIS (Urban Development Management Information System) of the Semarang City and used to generate a digital elevation model. We also obtained maps of existing (2011) and planned (2031) land uses and an annual land subsidence map taken from Semarang's Local Agency for Planning and Development (*Badan Perencanaan Pembangunan Daerah*/Bappeda). The map shows that annual land subsidence in the region ranges from 2 to 10 cm in the northern-eastern coastal areas.

To estimate the scale of SLR, we extracted data from previous studies [6,10,11,14,15] and selected to use 4 mm and 14 mm to quantify SLR in the region to the year 2031. We also conducted a field survey of 114 locations within the study area to gather information on potential *Rob* and backfilled lands and buildings. These survey locations are considered critical elevation points in the region and spread geographically across six sub districts, including Tugu, Semarang Barat, Semarang Utara, Semarang Timur, Gayamsari, and Genuk Sub District. We measured the extent of *Rob* in each of the survey locations and used these data to validate the predicted *Rob* extent in 2016 generated using our method described below. We also took photos during our field data collection for visual observation and comparison.

2.3. Methods

This study engages spatial analysis in GIS to map and predict areas of *Rob* and how it relates to the spatial planning of the region to the year 2031. We first generated a DEM from the 2000 topographic map of Semarang using the Inverse Distance Weighted (IDW) interpolation method (add a reference about IDW here). The spatial resolution of the DEM is one-meter.

To generate the *Rob* map, we formulated two scenarios of SLR in Semarang: an optimistic scenario with 4 mm SLR per year, and a pessimistic scenario with 14 mm SLR per year. The optimistic scenario is pitched slightly below the average of the recent projection by Julzarika [14], while the pessimistic scenario represents the upper bound foreseen by Ismunarti et al. [15]. Based on these two scenarios, we applied GIS map algebra to generate an updated DEM each year until 2031 by incorporating the average annual land subsidence data. This process produced 31 DEMs. The height unit of the DEM was converted to centimetre (UTM-based measurement). Further, map algebra was used to integrate the updated DEMs with the projected SLR scenarios to generate the *Rob* maps for 2016 and 2031.

We also used visual comparison with the field survey data to validate our analytical results. Field data collected from 114 locations were used to validate the *Rob* maps generated from the map algebra in GIS. By comparing the *Rob* map in 2016 with the survey data collected on the ground, we selected the scenario that better represent the ground truth.

Further, map overlay analyses were conducted to compare the predicted *Rob* extent under the selected scenario with the land use planning maps. We began by superimposing the land use map in 2011 on the projected map of *Rob* for 2031 to assess the impact of future *Rob* extent on current land uses, and then overlay the projected *Rob* map in 2031 on the Land Use Plan for 2031 contained in the Spatial Plan of Semarang City 2011–2031. This enables us to assess the extent to which the Spatial Plan for 2011–2031 has accommodated the potential hydro-meteorological hazard of *Rob* in the region.

3. Results

3.1. Projected areas of *Rob* under two scenarios

Fig. 2 shows the projected areas of *Rob* based on the optimistic and pessimistic scenarios for 2016 and 2031. Under the optimistic scenario, the inundation would reach 6.4 cm elevation in 2016 and 12.4 cm in 2031. Under the pessimistic scenario, the inundation would reach 22.4 cm and 43.5 cm in 2016 and 2031, respectively. Thus, according to the pessimistic scenario any areas below the Mean Sea Level (MSL) of 22.4 cm in 2016 and 43.5 in 2031 would be inundated.

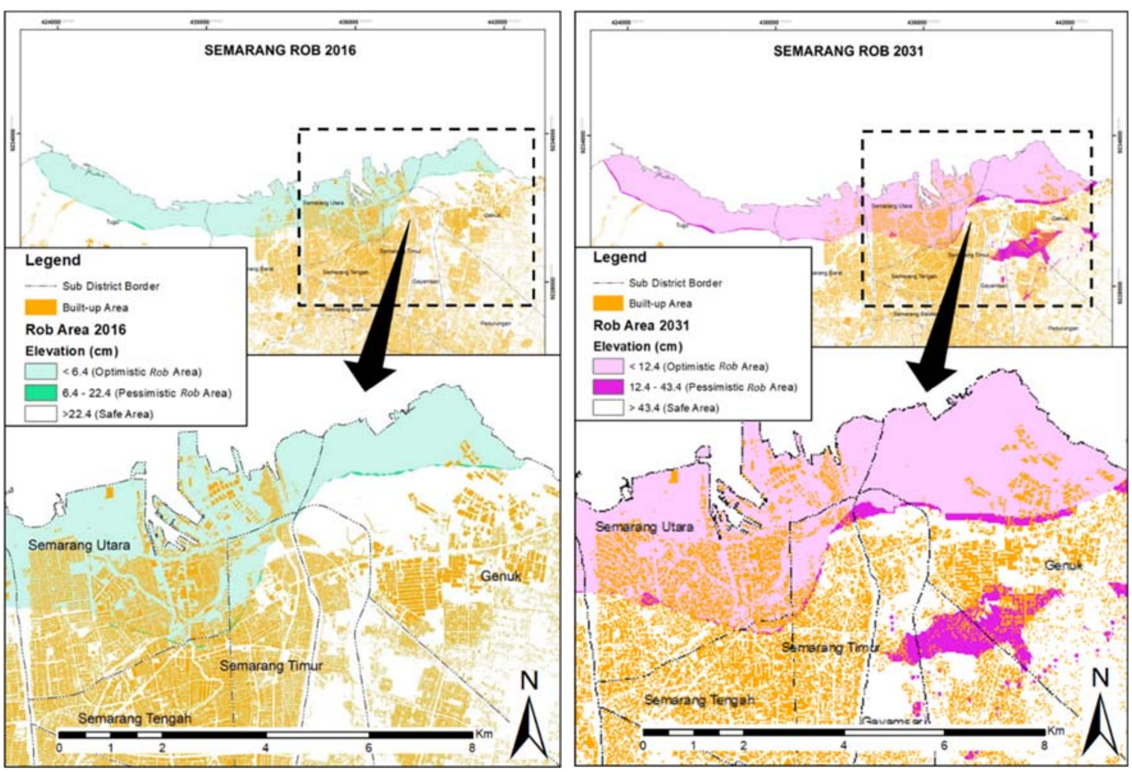

Figure 2 The projected areas of *Rob* for 2016 (left) and 2031 (right) based on the optimistic and pessimistic scenarios

Fig. 3 illustrates the difference of *Rob* areas projected for 2016 and 2031 under the two scenarios and urban villages being affected. In 2016, the areas would be 2645 ha and 2681 ha under the optimistic and pessimistic scenarios, respectively; these areas would increase to 3042 ha and 3363 ha in 2031 under the two scenarios respectively.

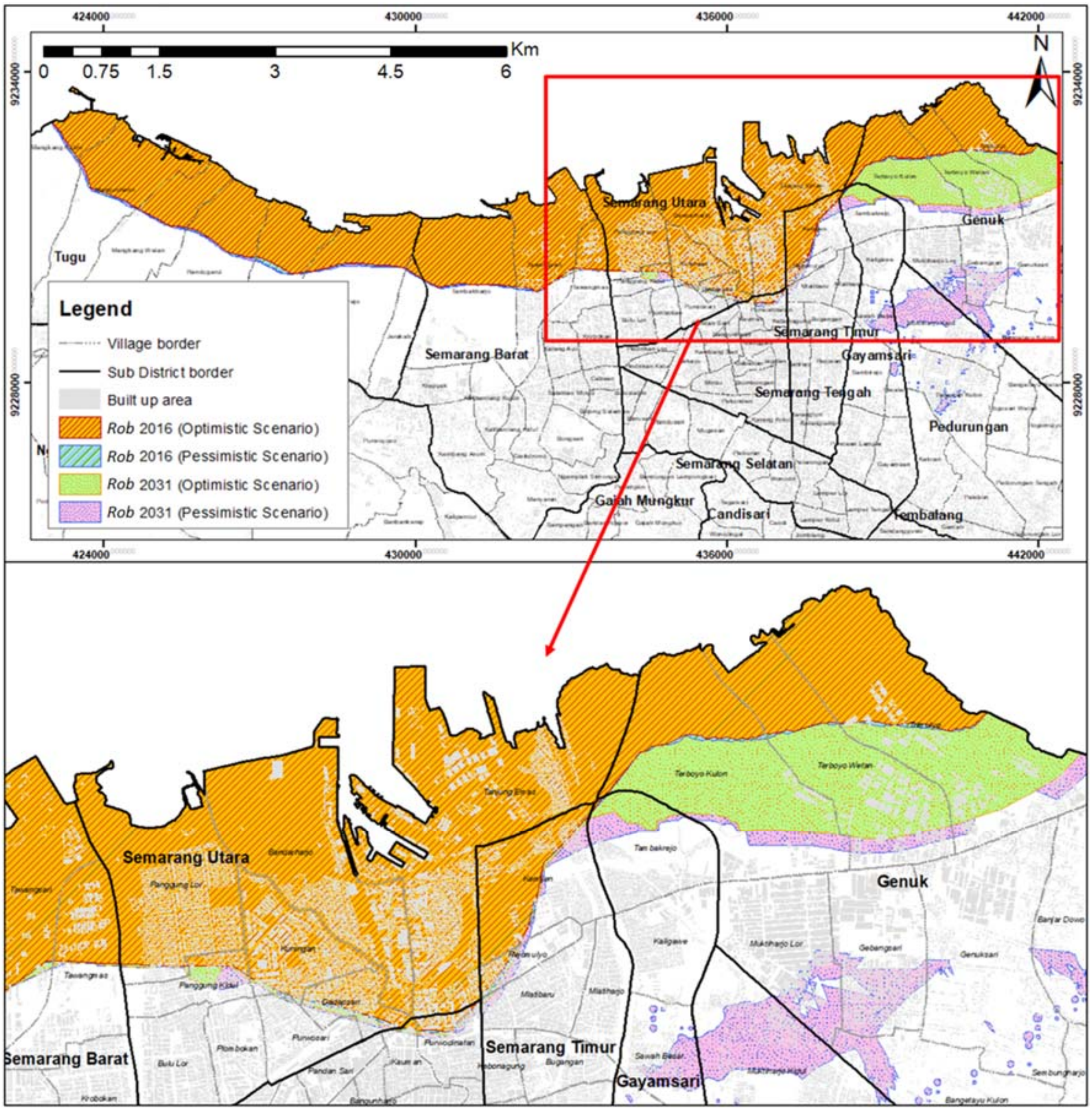

Figure 3 The spatial distribution of *Rob* areas projected for 2016 and 2031 under the two scenarios

Table 1 represents the projected areas of *Rob* for 2016 and 2031 under the two scenarios by urban villages (*kelurahan*). Under the pessimistic scenario, new locations that would be inundated would appear in some villages in the Genuk and Gayamsari Sub Districts by 2031, which are more than 6 km from the coast. Further research is required to evaluate its impact on these villages.

Table 1 The projected areas of *Rob* in 2016 and 2031 under the optimistic and pessimistic scenarios by urban villages

Sub District (*Kecamatan*)	Urban Village (*Kelurahan*)	2016 (ha)		2031 (ha)	
		Optimistic	Pessimistic	Optimistic	Pessimistic
Tugu	Jerakah	5.59	6.03	5.59	6.39
	Karang Anyar	128.93	134.75	128.99	135.99
	Mangkang Kulon	68.55	70.58	68.43	72.76
	Mangkang Wetan	113.30	114.37	113.22	116.24
	Mangunharjo	214.26	218.05	214.00	221.30
	Randugarut	142.55	145.98	142.50	148.92
	Tugurejo	156.76	159.88	156.83	163.42
Semarang Utara	Bandarharjo	222.74	222.74	222.79	222.79
	Dadapsari	26.43	28.10	32.20	33.86
	Kuningan	81.80	81.92	83.33	83.71
	Panggung Kidul	7.95	8.04	13.23	17.90
	Panggung Lor	180.71	180.83	182.01	182.17
	Purwosari	0.09	0.47	1.01	1.39
	Tanjung Emas	384.13	384.13	384.03	384.03
Semarang Timur	Kemijen	73.11	73.84	76.14	83.31
	Mlatibaru	0.01	0.15	0.61	2.63
	Rejomulyo	5.92	7.20	8.43	11.42
Semarang Tengah	Kauman	1.01	1.08	1.70	1.96
	Purwodinatan	6.97	7.73	9.26	11.27
Semarang Barat	Tambakharjo	246.13	248.92	246.18	250.62
	Tawangmas	49.35	49.39	50.32	50.81
	Tawangsari	239.00	239.95	241.35	243.23
Pedurungan	Muktiharjo Kidul	0.00	0.00	0.00	71.09
	Tlogosari Kulon	0.00	0.00	0.00	8.73
Genuk	Bangetayu Kulon	0.00	0.00	0.00	18.52
	Banjar Dowo	0.00	0.00	0.00	12.94
	Gebangsari	0.00	0.00	0.00	37.20
	Genuksari	0.00	0.00	0.00	5.63
	Muktiharjo Lor	0.00	0.00	0.00	27.11
	Terboyo Kulon	87.70	90.64	215.93	232.27
	Terboyo Wetan	55.98	56.94	165.98	178.74
	Trimulyo	146.08	148.63	259.39	271.73
Gayamsari	Sambirejo	0.00	0.00	0.00	0.21
	Sawah Besar	0.00	0.00	0.00	19.25
	Siwalan	0.00	0.00	0.00	3.09
	Tambakrejo	0.36	0.56	17.88	29.23

3.2. Validation of the projected areas of *Rob* in 2016 using field survey data

Among the 57 locations projected to be *Rob* areas in 2016 under both scenarios, 54 locations were verified to have *Rob* conditions which matches with the projected situation. Six other locations that were projected to be *Rob* areas in 2016 only under the pessimistic scenario were also verified on the ground. Amongst the 51 surveyed locations that were not projected as *Rob* areas under both scenarios, 14 locations were verified on the ground as Rob-affected areas caused by the abundance of sea water overflow on the dumping infill areas on which settlement had occurred; ten locations in Muktiharjo Lor and Genuk seemed beset by the lack of drainage systems, trapping the rain water but not experiencing sea water overflow; and seven sites along the road to the centre of the Genuk sub-district were Rob-affected as a result of sea water inflow through the drainage canals. Fig. 4 shows the spatial distribution of the surveyed locations and validation of the surveyed results compared to the projected *Rob* areas in 2016 under the two scenarios.

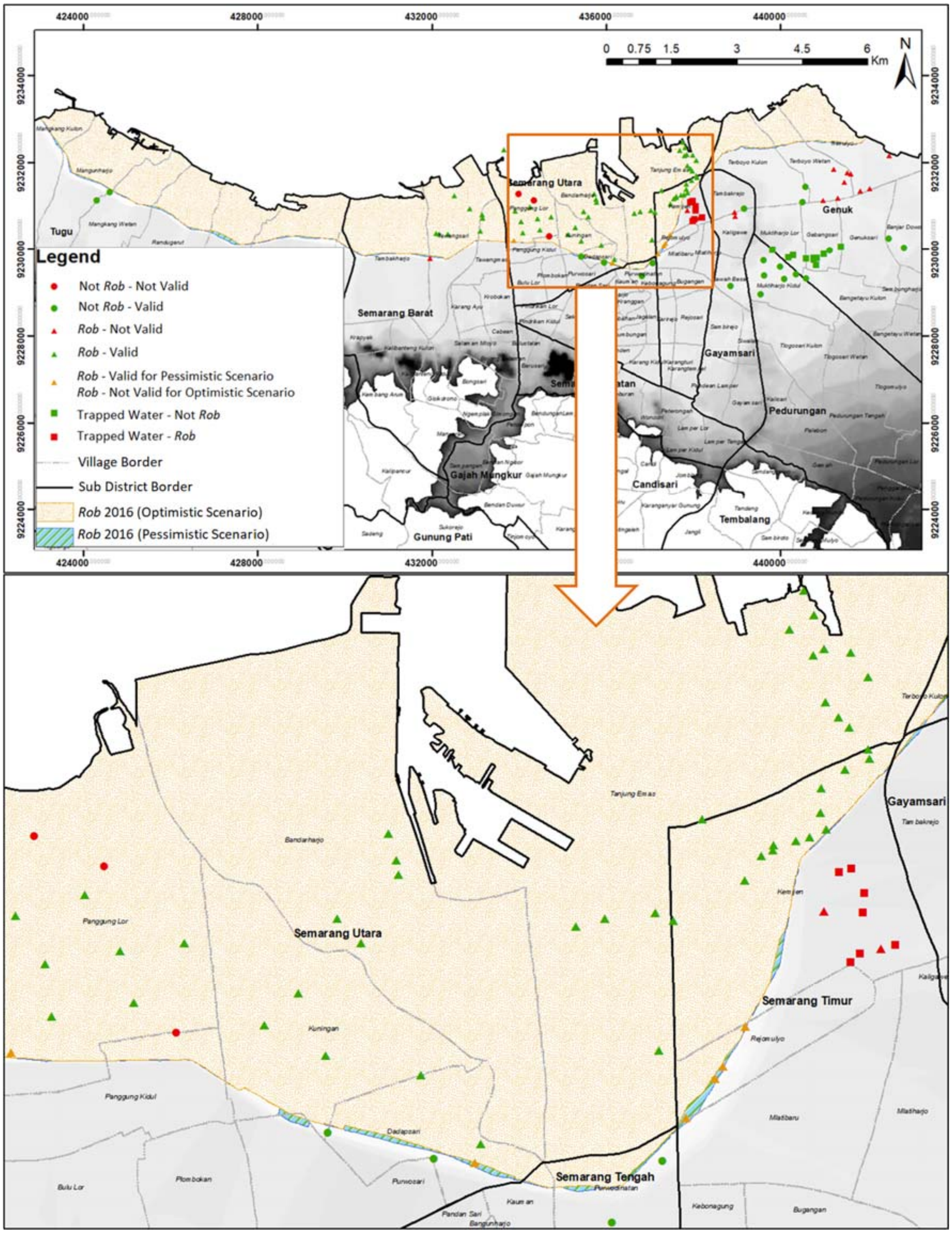

Figure 4 Validation of the projected *Rob* in 2016 using field survey data

Given that the projected Rob areas in 2016 under the pessimistic scenario matches better with the ground survey result (with a total of 90 matching locations out of the 114 locations being surveyed, compared to 84 matching locations under the optimistic scenario), it appears that the pessimistic scenario suits better with the empirical ground truth. Therefore, the *Rob* map for 2031 under the pessimistic scenario was selected for further comparison with the Semarang Land Use Plan 2011–2031.

In the Semarang Timur, Gayamsari, and Semarang Barat Sub-districts, *Rob* has damaged various road segments (Fig. 5). They cannot be used anymore because the ponded water is high and the road condition is poor. In Kemijen Village, the height of canal water channel exceeds road surface as can be seen in Fig. 5 (top right).

Figure 5 *Rob* areas in Semarang Barat, Semarang Timur, and Gayamsari Sub Districts

The height of *Rob* areas in Genuk Sub District ranges from 5 to 20 cm, but can reach to as high as 30–100 cm on the highest tide. The areas being affected are located in three urban villages: Trimulyo and Gebangsari which are largely settlement areas as, and Terboyo Kulon that is used by industrial activities. Besides, Genuk Sub District has experienced subsequent land subsidence caused by groundwater withdrawal of about 30–50 cm over the last five years [12]. This is the reason why the main roads in this sub district were back filled by up to about 50 cm on average. Fig. 6 shows some of these sites we visited during the field survey in 2016.

Figure 6 The inundated and *Rob* areas in Genuk Sub District

Fig. 7 presents some *Rob* areas in Semarang Utara Sub District. This area has experienced an even worse land subsidence history compared with the other areas, resulting in land subsidence of about 30–80 cm. The field observation reveals that most of the land have been backfilled up by 15–60 cm in order to make the road higher than the water surface. Meanwhile, land around buildings have also been backfilled and raised by 30–100 cm. Nevertheless, *Rob* was still found to be severely impacting settlements, industrial areas, and private and public offices. The height of inundation and *Rob* ranges from 5 to 20 cm.

Figure 7 The *Rob* areas in Semarang Utara Sub District

3.3. Projected *Rob* areas in 2031 under the pessimistic scenario

Under the pessimistic scenario, *Rob* height will reach 43.4 cm by 2031. Fig. 8 illustrates the Rob map in 2031. The negative pixel value of −310 cm represents the depth below sea level and the positive pixel value of up to 4899 cm shows the highest elevation of the study area. As such, area with negative elevation value would be permanently *Rob* (sinking) and those with a value larger than 43.4 cm would be considered as safe areas (Fig. 8).

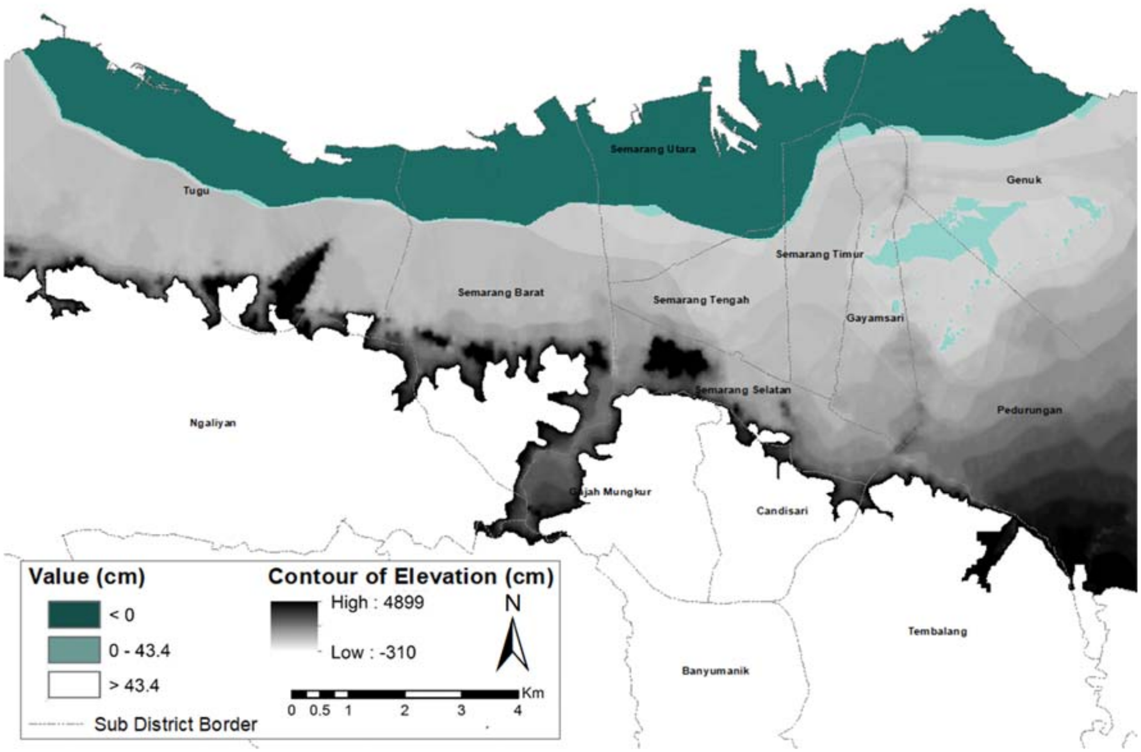

Figure 8 The projected areas of *Rob* in Semarang for 2031

We reclassified the elevation values into three categories showing areas of permanently *Rob* (elevation < 0 cm), temporarily *Rob* (0–43.4 cm), and safe area (> 43.4 cm). By superimposing the categorized *Rob* map upon the administrative boundary map of sub districts and urban villages, a detailed distribution of the permanently and temporarily *Rob* areas by sub district and urban village were computed (Table 2).

Table 2 The projection of temporarily and permanently-affected *Rob* areas by sub district and urban village of Semarang for 2031

Sub District	Temporarily *Rob* area		Permanently *Rob* area		Total *Rob* Area
	Urban Village	Ha	Urban Village	Ha	*(Ha)*
Pedurungan	MuktiharjoKidul	63.50			**71.81**
	TlogosariKulon	3.55			
Genuk	BangetayuKulon	15.29	TerboyoKulon	198.21	**67.05**
	Banjar Dowo	9.91	TerboyoWetan	153.18	
	Gebangsari	31.66	Trimulyo	236.80	
	Genuksari	3.20			
	MuktiharjoLor	21.86			

	TerboyoKulon	14.67			
	TerboyoWetan	10.54			
	Trimulyo	9.48			
Semarang Barat	Tambakharjo	2.52	Tambakharjo	243.07	**499.05**
	Tawangmas	0.04	Tawangmas	44.16	
	Tawangsari	0.53	Tawangsari	208.74	
Semarang Tengah	Kauman	0.01	Kauman	1.27	**10.87**
	Purwodinatan	0.77	Purwodinatan	8.82	
Semarang Timur	Kemijen	3.39	Kemijen	73.54	**88.88**
	Mlatibaru	1.57	Mlatibaru	0.63	
	Rejomulyo	1.41	Rejomulyo	8.35	
Gayamsari	Sambirejo	0.03	Tambakrejo	11.96	**41.09**
	SawahBesar	13.84			
	Siwalan	1.95			
	Tambakrejo	13.31			
Semarang Utara	Dadapsari	1.45	Bandarharjo	201.58	**800.19**
	Kuningan	0.06	Dadapsari	28.63	
	PanggungKidul	7.68	Kuningan	71.42	
	PanggungLor	0.12	PanggungKidul	7.54	
	Purwosari	0.25	PanggungLor	153.56	
			Purwosari	0.70	
			TanjungEmas	327.20	
Tugu	Jerakah	0.35	Jerakah	5.88	**826.61**
	KarangAnyar	6.90	KarangAnyar	121.52	
	MangkangKulon	3.08	MangkangKulon	62.70	
	MangkangWetan	2.19	MangkangWetan	113.27	
	Mangunharjo	5.34	Mangunharjo	204.42	
	Randugarut	4.21	Randugarut	137.17	
	Tugurejo	4.14	Tugurejo	155.47	
Total Area					**3,038.55**

The sub districts potentially being threatened by *Rob* range from the largest to smallest areas are, respectively, Tugu (826.61 ha), Semarang Utara (800.19 ha), Genuk (704.80 ha), Semarang Barat (499.05 ha), Semarang Timur (88.88 ha), Pedurungan (67.05 ha), Gayamsari (41.09 ha), and Semarang Tengah (10.87 ha).

3.4. Comparison between the land use plan 2011–2031 and the projected *Rob* for 2031

Fig. 9 illustrates the overlay results of the projected *Rob* areas for 2031 with the current land use in 2011 (top) and with the 2031 land use plan (bottom), respectively. Table 3 shows that the potential *Rob* areas in 2031 account for 8.2% (3059 ha) of the total area of Semarang City (37,367 ha). Among them, 60.6% are built-up, consisting of 17.8% industrial areas, 11.2% residential areas, 15.7% trade and service areas, 9.9% public terminals, and 6.1% mixed use areas. The extent of *Rob* increases 15.2% from that of 2011. Although the land use plan has allocated areas for conservation, the increase of built-up space projected in the plan indicates that the potential hydro-meteorological hazard is still hardly acknowledged.

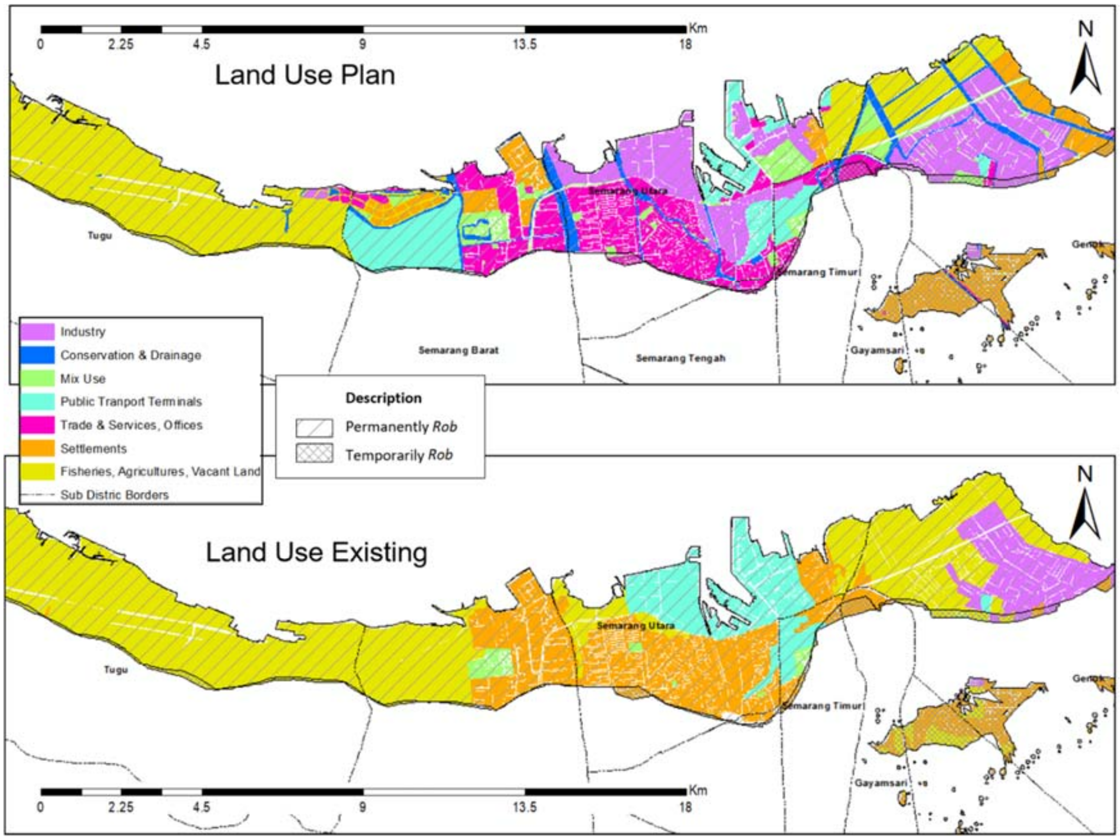

Figure 9 Overlay of the projected *Rob* for 2031 and the land use maps in 2011 (top) and 2031 (bottom)

Table 3. *Rob* areas of Semarang in 2016 and 2031 by land use

Land use	Existing 2016 (ha)			Plan 2031 (ha)		
	Temporarily *Rob* areas	Permanently *Rob* areas	Total	Temporarily *Rob* areas	Permanently *Rob* areas	Total
Industry	16.31	219.19	**235.50**	24.20	519.54	**543.74**
Settlement	154.96	663.95	**818.91**	155.01	186.31	**341.32**
Trade and services	0.97	6.83	**7.79**	33.90	444.72	**478.63**
Public transport facilities	0.62	314.35	**314.96**	3.24	298.27	**301.51**
Mix use	1.34	40.20	**41.54**	7.17	180.31	**187.48**
Conservation	-	-	**-**	9.04	161.14	**170.18**
Agriculture	84.58	1534.60	**1,619.18**	26.20	1,009.89	**1,036.09**
Total	**258.77**	**2,779.11**	**3,037.88**	**258.77**	**2,800.18**	**3,058.95**
Built-up areas	172.85	1,204.31	**1,377.17**	223.52	1,629.16	**1,852.68**
Non-built-up areas	85.91	1,574.80	**1,660.71**	35.24	1,171.03	**1,206.27**
% built-up areas			45.30			60.60%
% non-built-up areas			54.70			39.40%
Total			**100%**			**100%**

Indeed, the Land Use Plan 2011–2031 features higher building density for more intensive use. Although areas for residential settlement will decrease from 818.91 in 2016 to 341.32 ha in 2031, areas for secondary and territory industries will increase from 235.50 ha to 543.74 ha and from 7.79 ha to 478.63 ha, respectively, over the same period. Besides, the mixed-use area will also grow from 41.54 ha to 170.18 ha. The fact that there is a shift from residential development into more intensive land uses – industry, trade and services, and mixed uses –

indicates that the potential hydro-meteorological hazard has not been considered by decision-makers and planners.

Our results also show that the permanently *Rob* areas lying under mean sea level will reach 2800 ha by 2031. Moreover, about 58.17% of those areas represent built-up areas, an increase of 35% from 2016. Serious endeavours by the city government are needed to render the activities conducted in those areas more sustainable.

4. Discussion

This study reconfirmed findings from existing research [33,36] that Indonesian spatial planning at local level has not taken into account the significant impact of hydro-meteorological hazards on its future development. The method in the case of Semarang City might also be replicated in other coastal cities in Indonesia. Semarang, as the capital of Central Java Province, plays a significant role in the development of Java and Indonesia. Together with Jakarta and Surabaya as the largest and second largest cities located along the Java coast, Semarang serves as a hub for the development of its hinterland. Any physical and environmental problems occurring in Semarang will potentially affect the entire region.

The northern coastal areas of Semarang such as the Genuk Sub District were historically areas for manufacturing industry. However, these areas are heavily affected by *Rob*. The rate of land subsidence is also the highest at 10 cm per year. Field observation in 2016 confirmed that many industries were closed and moved away from Semarang. It is likely due to this reason the Semarang government no longer claims industry as the main function of the city. Instead, the government aims to transform from manufacturing to trade and services as the main function which is stated in its Regional Medium-term Local Development Plan (*Rencana Pembangunan Jangka Menengah Daerah*/RPJMD) 2016–2021.

In Semarang, *Rob* is mainly caused by SLR affected by climate change at the global scale and land subsidence at local scale, the latter being the result of intensive human activities and development. As the capital of Central Java Province, Semarang has attracted many intensive human activities such as trades, hotels, offices and industries, all of which demand large amount of water use, which are also growing significantly over time. According to Susanto et al. [56], ground water supply for industries, hotels, and restaurants accounts for 90% of Semarang's total water consumption. The extraction of ground water would certainly accelerate the rate of land subsidence, which was also verified by our field survey in 2016.

Furthermore, the comparison between the projected *Rob* areas and the Land Use Plan 2011–2031 reveals that some land uses with less intensive activities are planned for more intensive uses, for example, protective embankments are planned for industry, settlements, trading zones, or public transport facilities, settlements are planned for trading zones, and so on. However, these constructions are located in the projected areas of *Rob*; some of them are even located in the permanently *Rob* areas. It is also important to notice that in some locations the enclave areas predicted to be *Rob* are further away from the coast line. They are located in several urban villages of Genuk, Gayamsari, and Pedurungan Sub Districts wherein present land uses are devoted to vacant land, settlement and trade. Some of these areas are planned to become industrial areas in the current Spatial Plan of the region, indicating that the current land use plan did not the impact of hydro-meteorological hazard on the region.

Should the current land use plan is implemented, special treatment method would be required to provide structural or non-structural mitigation to avoid any negative impacts on the region.

The methodology reported in this study is useful in predicting the anticipated vulnerability of areas based on SLR and land subsidence. The projected map of *Rob* areas can describe the scope of vulnerable areas affected by hydro-meteorological hazard. Besides, it is also capable of assessing the extent to which the City Spatial Plan has adequately considered the issue when preparing the plan.

This study is not without limitation. One key limitation in this research concerns about data availability and accuracy. This remains as a major problem in developing countries like Indonesia. Regardless of Semarang being one of the largest scale cities in Java, it is still limited data available and no authentic information available to verify the data accuracy. For example, there is no reliable land subsidence map available from any government agencies that we can use in this study, therefore, we applied map algebra to generate the data from topographic map under different SLR scenarios.

5. Conclusion

This study concludes that the Land Use Plan within the Spatial Plan 2011–2031 of Semarang City has not accommodated potential hydro-meteorological hazard. The types of land uses planned in the predicted areas of *Rob* in 2031 have more intensive activities than the current land use types. The built-up areas projected in 2031 are also more spread out than those in the current situation. The high risk imposed by *Rob* are mainly located in Tugu, Semarang Utara and Semarang Barat Sub-Districts where land use types are dominated by industry, trade and services, and public transportation facilities. However, the risks in Tugu Sub District are less than in others as its land use in 2031 is planned to be dominated by fisheries, agriculture, and vacant lands, including those set aside for embankments.

There are some weaknesses relating to the method employed in this project. First, the land subsidence information, though the best available at the time, was not altogether appropriate because of data limitations. The second weakness relates to the validation with limited sample size and its spatial distribution. A systematic sampling approach of the entire study area would be preferable, however, we only surveyed 114 locations due to both time and budget constraints. By and large, the output from the model has addressed the defined research questions. The methodology can be used by urban and regional planners to advance their planning practices. By employing this spatial analytical approach, planners can develop suitable programs to reduce negative impacts of city development located in areas prone to *Rob*. Any areas projected to be Rob areas should be regarded as 'hazardous' and constrained from urban development.

Future research will explore indigenous activities or innovative ways in which local people deal with the problem of *Rob*. For local Indonesians, our results should be useful for planners to review the contents of the Spatial Plan for cities located not only in the north coastal areas of Java, but those elsewhere in the archipelago which face hydro-meteorological hazards.

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