Performance of the Geometric-Historic Method for Estimating Land Subsidence in Urban Areas of Indonesia

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Key words: Land Subsidence, GPS, InSAR, Geometric-Historic, Indonesia

SUMMARY

Several large urban areas in Indonesia, i.e. Jakarta, Bandung and Semarang, have experienced land subsidence for at least more than a decade. Land subsidence in these cities has been estimated using several geodetic methods, such as leveling, GPS survey, InSAR, and/or microgravity. The results obtained from these techniques over the period between 1982 and 2011 show that observed subsidence rates in Jakarta are about 1 to 15 cm/year, and can reach up to 20-28 cm/year at certain location and certain period. In Bandung basin, it was found that during the period between 2000 and 2011, several locations have experienced subsidence, with an average rate of about 8 cm/year and can reach up to about 23 cm/year. In Semarang, land subsidences with rates of up to about 19 cm/year were observed during the period of 1999 up to 2011.

In this paper, the geometric-historic method for observing and estimating land subsidence is introduced. This method is based on observation of land subsidence impacts in the field. By measuring the vertical displacement caused by land subsidence effect on the impacted object or structure, combined with historical and interview data, then the subsidence rate can be calculated. This method has been implemented to estimate subsidence rates at several locations in Jakarta, Bandung and Semarang, and the obtained rates have been compared with GPS and InSAR derived subsidence rates. The strength and limitation of this geometric-historic method is also presented and discussed.

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1. INTRODUCTION

Land subsidence is the downward displacement of the land surface relative to certain reference surface, such as mean sea level (MSL) or reference ellipsoid, or relative to a certain assumed stable point (*Abidin et al*., 2013a). This hazard phenomena can be caused by natural and/or human activities, such as tectonic activities, underground mining activities, excessive groundwater or oil/gas extraction, natural consolidation of alluvium soil, and load of constructions.

It has been reported that many large urban areas (cities) are affected by this natural-anthropogenic hazard, such as Bangkok (*Phien-wej et al.,* 2006), Taipei (*Chen et al.,* 2007), Osaka (*Murayama,* 1970), Tokyo (*Ishii et al.,* 1970), Shanghai (*Chai et al.,* 2004), Kerman, Iran (et al., 2010), Houston (*Buckley et al.,* 2003), and Mexico City (*Cabral-Cano et al.,* 2008). In Indonesia, this silent-type hazard have occurred in Jakarta (*Abidin et al*., 2001; 2008a; 2010a; 2011), Bandung (*Abidin et al.,* 2008b; 2009; 2012a; 2013b), and Semarang (*Abidin et al.,* 2010b; 2012b). Considering significant lowering in observed groundwater levels, several other cities in Indonesia are also predicted to experience land subsidence, such as Surabaya, Denpasar and Medan. However, systematic geodetic observations are required to verifiy that prediction.

The impacts of land subsidence in urban areas are quite numerous and the resulting losses cannot be under estimated (see Figure 1). Cracking of buildings and infrastructure, and wider expansion of coastal and inland flooding areas, are the common impacts than can be seen in the field. Besides affecting land surface and infrastructure, land subsidence will also deteriorate the quality of living environment and life (e.g. health and sanitation condition) in the affected areas. Development and maintenance costs of infrastructures in land subsidence affected areas will usually be higher than the normal situation. Social and environmental costs due to direct and indirect impacts of land subsidence are usually significant.

In general, information related to characteristics of land subsidence is important for urban planning and development activities, environmental management, and risk assessment efforts. Therefore, systematic and continuous monitoring of land subsidence in urban areas is obviously needed and critical to the welfare of the peoples.

Land subsidence magnitudes and rates can be estimated using several geodetic measurement techniques, such as Leveling surveys, GPS (Global Positioning System) surveys, INSAR (Interferometric Synthetic Aperture Radar), and microgravity surveys. With sufficient data and information, the temporal and spatial variations of land subsidence in certain area can also be studied. Typical strength and limitation of those geodetic methods (i.e. Leveling surveys, GPS surveys, InSAR, and Microgravity surveys) in deriving land subsidence characteristics in urban area are given in Table 1.

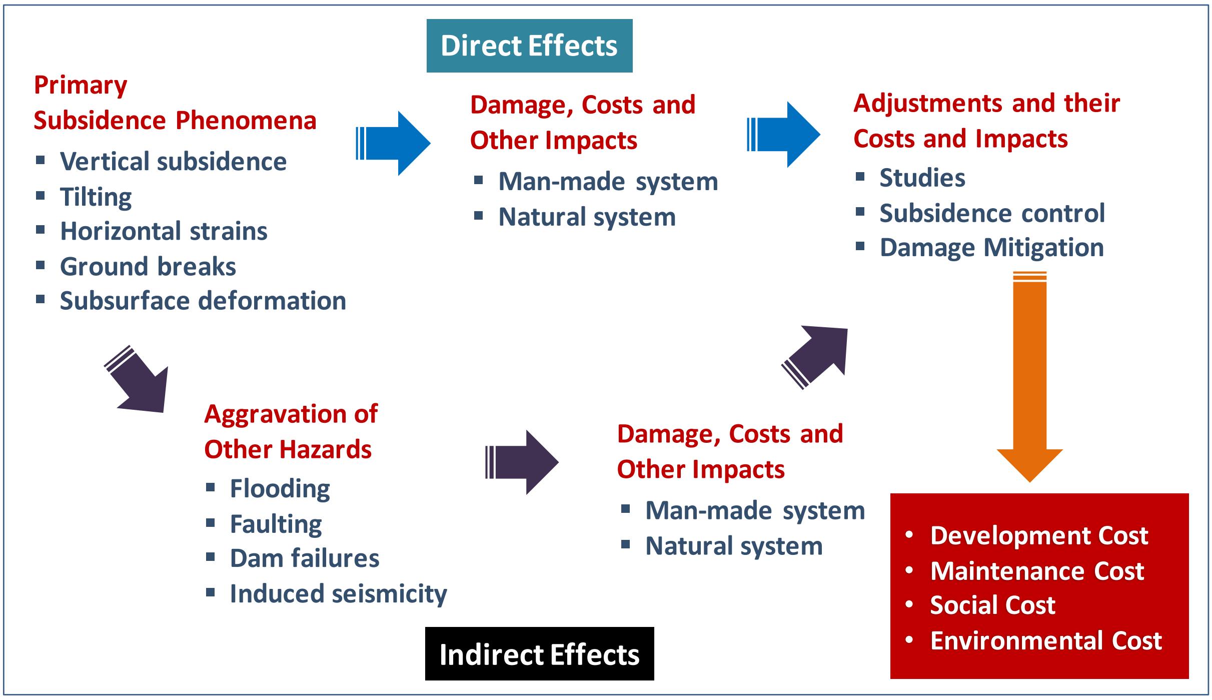

Figure 1. Losses due to land subsidence, after *Viets* (2010).

Table 1. Typical strength and limitation of geodetic method for land subsidence study in urban areas, from Abidin et al. (2013a)

	Leveling surveys	GPS surveys	InSAR	Microgravity
LS information	point-wise	point-wise	continuous	point-wise
Spatial coverage	local	local to regional	local to regional	local
Temporal coverage	user dependent	user dependent	images availability dependent	user dependent
Ground benchmark	required	required	not required	required
Data acquisition (survey)	day time and weather dependent	day and night, weather independent	dependent on satellite passes in the region	day and night, weather dependent
Typical limitation	laborious and time consuming	signal obstruction by buildings, infrastructures and trees	poor image coherence due to land use and land cover dynamics	requires stringent observation strategy and quite costly
Typical accuracy level of LS	mm (relative)	mm-cm (relative)	mm-cm (relative)	mm-cm (relative)

In this paper, the geometric-historic method for studying land subsidence, which is not yet widely used in geodetic community, will be explained and dicussed using the results obtained in urban areas of Indonesia, i.e. Jakarta, Bandung, and Semarang (see Figure 2). These cities are well known for have been experiencing land subsidence for decades.

Figure 2. Large cities of Indonesia affected by land subsidence, i.e. Jakarta, Bandung and Semarang.

Information on land subsidence characteristics in Jakarta can be obtained in *Abidin et* al., (2001, 2008a, 2010a, 2011) and *Ng et al.* (2012). In general, the observed subsidence rates in Jakarta from leveling surveys, GPS surveys and InSAR technique over the period between 1982 and 2012, are about 1 to 15 cm/year with spatial and temporal variations. In Bandung basin, using GPS surveys and InSAR, it was observed that between 2000 and 2011, several locations in the Bandung basin have experienced land subsidence, with an average rate of about –8 cm/year (*Abidin et al.* 2008b; 2009; 2012a; *Sumantyo et al.,* 2012). In Semarang, based on results from Levelling surveys, GPS surveys, Microgravity surveys, and InSAR technique, land subsidence with rates of up to about 19 cm/year were observed during the period of 1999 up to 2011 (*Sutanta et al.,* 2005; *Marfai and King,* 2007; *Abidin et al.,* 2010b; 2012b; *Kuehn et al.,* 2009; *Lubis et al.,* 2011; *Supriyadi,* 2008, *Fukuda et al.,* 2008).

In this paper, whenever possible the land subsidence characteristics estimated using the geometric-historic method, will be compared with those obtained from other geodetic measurement techniques.

2. PRINCIPLE OF GEOMETRIC-HISTORIC METHOD

The geometric-historic method is actually the newest method introduced in estimating land subsidence in Jakarta, Semarang and Bandung. This method (see Figure 3) is based on field measurement, historical and interview data of subsidence affected object observed in the field. In estimating subsidence (average) rate, linear rate assumption is used in this method.

This method can be applied to various subsidence affected objects and features that are found in the field, such as houses, bridges and other infrastructures as examples shown in Figure 4. The magnitude of observed subsidence can be directly measured using measuring tapes, or indirectly using ETS (Electronic Total Station). The time period related to this subsidence can be based on the historical or documented data (if any, like in the case of bridge and building), or can be extracted from interviewing the peoples (e.g. in case of house).

In land subsidence study in the urban areas, the geometric-historic method should be used in complimentary manner with other geodetic measurement techniques, and sometimes can also be used for validating the derived subsidence given by other methods. The geometric-historic method can estimate the subsidence rates at certain location from only a single measurement epoch. Moreover, this method can estimate the subsidence rates at location which are not accessible by other geodetic techniques.

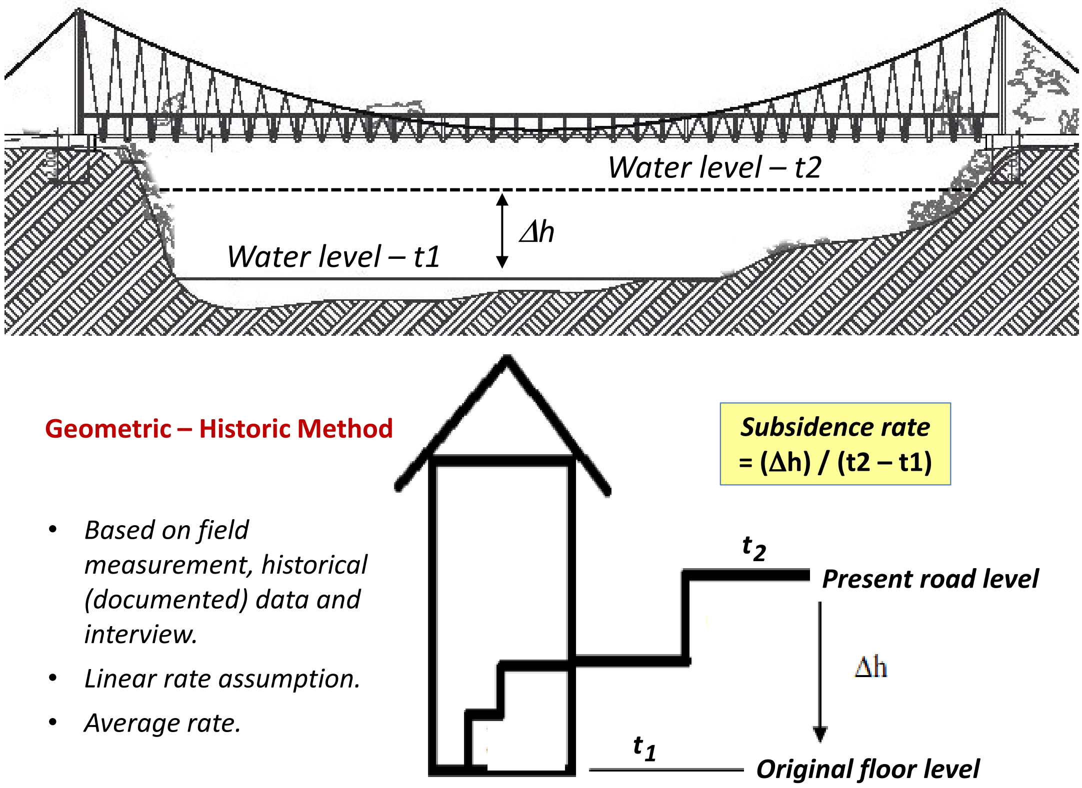

Figure 3. Principle of geometric-historic method for land subsidence estimation, for the cases of bridge and house affected by land subsidence (upper and lower sketches).

Figure 4. Examples of land subsidence affected features in Semarang, Jakarta and Bandung.

The accuracy of subsidence information derived from geometric-historic will strongly depend on how accurate the vertical displacement and the time period can be estimated from field measurement and historical (documented) and interview data. It requires good field surveyors, which have good geometrical insights into the impacts of land subsidence on various objects and features in the field, and also have good communication skill for interviewing peoples.

3. LAND SUBSIDENCE DERIVED USING GEOMETRIC-HISTORIC METHOD

Land subsidence in urban areas of Indonesia (i.e. Jakarta, Bandung and Semarang), has been studied using the geometric-historic method along with other geodetic measurement techniques, such as Leveling surveys, GPS surveys, InSAR and Microgravity surveys.

In Semarang, the geometric-historic method has been used to estimate subsidence rates at several observation location as shown in Figure 5. In general, the derived subsidence rates is comparable in accuracy with subsidence rates derived by GPS surveys in nearby locations. The differences in this case are about 1-2 cm/year or less, as shown in Figure 6. Spatial variation of subsidence rates as obtained by this method is depicted in Figure 7.

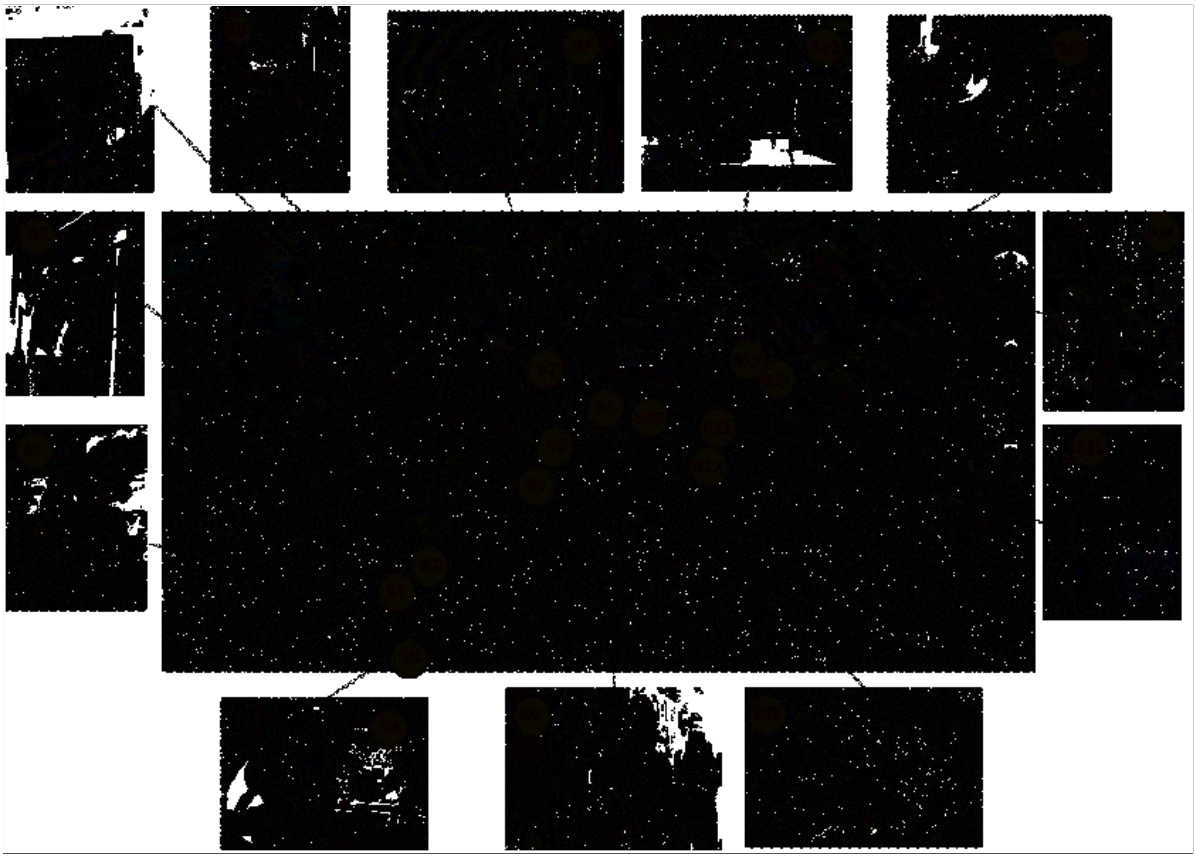

Figure 5. Implementation of the geometric-historic method for estimating land subsidence rates at several location in Semarang in 2012, from *Yuwono* (2013).

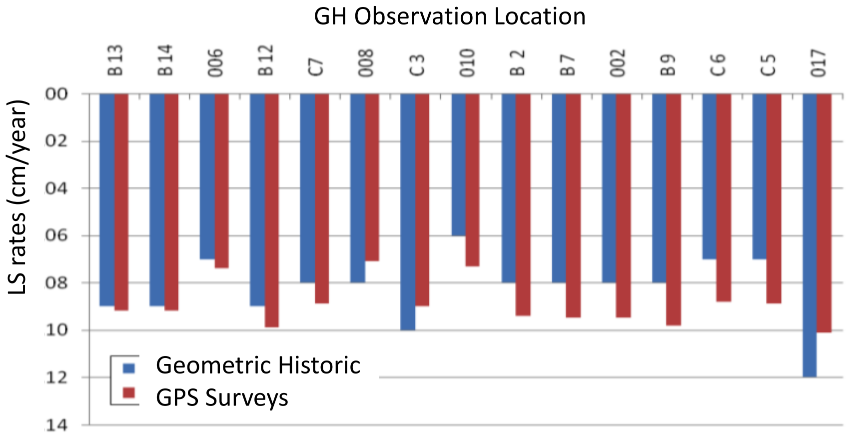

Figure 6. Comparison of land subsidence (LS) rates in Semarang, between those derived by GPS surveys and the geometric-historic methods; after *Yuwono* (2013).

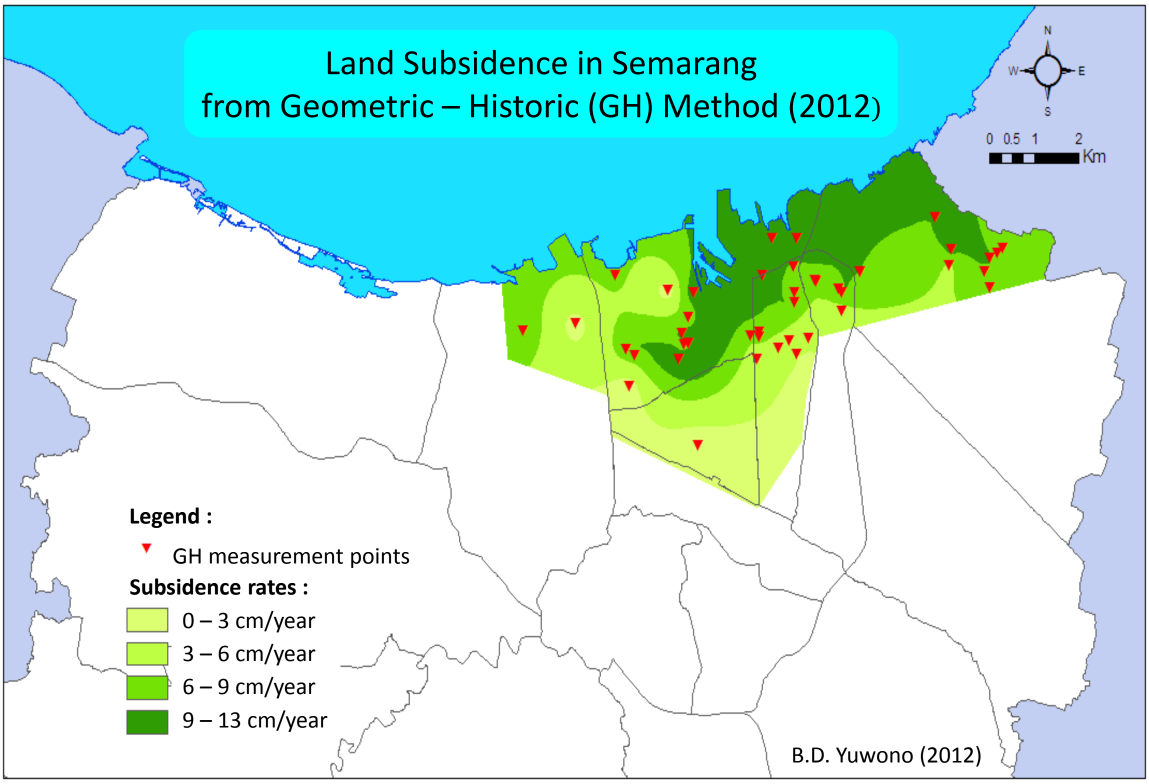

Figure 7. Land subsidence rates in Semarang in 2012,
as derived from the geometric-historic method, after *Yuwono* (2013).

In Bandung, the geometric-historic method has also been implemented to estimate land subsidence rates at several locations. In this case, the implementation is focused in the areas which are indicated to have significant subsidence rates from previous GPS surveys and InSAR data processing. The results are shown in Table 2.

Table 2. Land subsidence rates derived by the Geometric-Historic (GH) method, in comparison with InSAR and GPS surveys derived rates; after Gumilar (2013).

<table>
<tr><th rowspan="2">No</th><th rowspan="2">Latitude</th><th rowspan="2">Longitude</th><th colspan="3">Subsidence Rates (cm/year)</th><th rowspan="2">Distance (m) from GPS to GH/InSAR location</th></tr>
<tr><th>GH</th><th>InSAR</th><th>GPS Surveys</th></tr>
<tr><td>1</td><td>6° 58' 52,63199" S</td><td>107° 37' 13,89601" E</td><td>4.6</td><td>6.5</td><td rowspan="7">5.9</td><td>246</td></tr>
<tr><td>2</td><td>6° 58' 51,43799" S</td><td>107° 37' 13,23600" E</td><td>4.7</td><td>6.2</td><td>246</td></tr>
<tr><td>3</td><td>6° 58' 48,32401" S</td><td>107° 37' 12,01799" E</td><td>5.0</td><td>6.6</td><td>214</td></tr>
<tr><td>4</td><td>6° 58' 44,76599" S</td><td>107° 37' 11,49001" E</td><td>4.7</td><td>7.0</td><td>156</td></tr>
<tr><td>5</td><td>6° 58' 44,01600" S</td><td>107° 37' 10,95001" E</td><td>3.1</td><td>7.0</td><td>194</td></tr>
<tr><td>6</td><td>6° 58' 24,19201" S</td><td>107° 37' 10,77601" E</td><td>2.3</td><td>7.3</td><td>152</td></tr>
<tr><td>7</td><td>6° 59' 12,84599" S</td><td>107° 37' 57,69601" E</td><td>4.1</td><td>7.5</td><td>179</td></tr>
<tr><td>8</td><td>6° 55' 19,44601" S</td><td>107° 33' 25,83601" E</td><td>10.9</td><td>12.7</td><td>14.2</td><td>251</td></tr>
<tr><td>9</td><td>6° 55' 19,57199" S</td><td>107° 33' 20,89799" E</td><td>7.7</td><td>14.4</td><td rowspan="4">16.9</td><td>532</td></tr>
<tr><td>10</td><td>6° 55' 19,69200" S</td><td>107° 33' 19,95599" E</td><td>9.2</td><td>14.8</td><td>576</td></tr>
<tr><td>11</td><td>6° 55' 19,51201" S</td><td>107° 33' 18,45599" E</td><td>8.3</td><td>15.5</td><td>543</td></tr>
<tr><td>12</td><td>6° 54' 16,05493" S</td><td>107° 32' 02,31197" E</td><td>8.3</td><td>6.7</td><td>568</td></tr>
<tr><td>13</td><td>6° 54' 54,92291" S</td><td>107° 32' 59,13471" E</td><td>7.1</td><td>15.5</td><td>15.3</td><td>544</td></tr>
<tr><td>14</td><td>7° 00' 08,62226" S</td><td>107° 44' 54,47931" E</td><td>5.3</td><td>8.5</td><td>1.9</td><td>146</td></tr>
<tr><td>15</td><td>7° 00' 13,95599" S</td><td>107° 44' 55,38570" E</td><td>4.3</td><td>8.1</td><td rowspan="2">4.3</td><td>58</td></tr>
<tr><td>16</td><td>7° 00' 41,21876" S</td><td>107° 44' 53,36205" E</td><td>5.3</td><td>6.9</td><td>80</td></tr>
<tr><td>17</td><td>7° 01' 06,17634" S</td><td>107° 46' 14,93603" E</td><td>3.5</td><td>1.9</td><td>4.4</td><td>114</td></tr>
<tr><td>18</td><td>6° 58' 40,53552" S</td><td>107° 45' 04,70152" E</td><td>9.2</td><td>5.6</td><td>5.1</td><td>98</td></tr>
<tr><td>19</td><td>6° 57' 53,82708" S</td><td>107° 48' 06,86046" E</td><td>8</td><td>6</td><td>3.9</td><td>562</td></tr>
<tr><td>20</td><td>6° 56' 23,16270" S</td><td>107° 41' 24,19705" E</td><td>9</td><td>7.2</td><td rowspan="7">9.2</td><td>173</td></tr>
<tr><td>21</td><td>6° 56' 31,23591" S</td><td>107° 41' 34,66036" E</td><td>7.3</td><td>8.9</td><td>654</td></tr>
<tr><td>22</td><td>6° 56' 31,77820" S</td><td>107° 41' 30,82202" E</td><td>3.7</td><td>8.9</td><td>643</td></tr>
<tr><td>23</td><td>6° 56' 33,48803" S</td><td>107° 41' 27,60885" E</td><td>8.8</td><td>8.9</td><td>678</td></tr>
<tr><td>24</td><td>6° 56' 36,97421" S</td><td>107° 41' 20,92241" E</td><td>6.7</td><td>8.9</td><td>690</td></tr>
<tr><td>25</td><td>6° 56' 42,15138" S</td><td>107° 41' 20,07286" E</td><td>4.3</td><td>9.2</td><td>632</td></tr>
<tr><td>26</td><td>6° 57' 52,64636" S</td><td>107° 37' 22,51517" E</td><td>11.7</td><td>11.8</td><td>709</td></tr>
<tr><td>27</td><td>6° 58' 08,57401" S</td><td>107° 37' 59,94776" E</td><td>5</td><td>8.4</td><td>9.3</td><td>15</td></tr>
<tr><td>28</td><td>6° 59' 50,29790" S</td><td>107° 37' 19,78455" E</td><td>5.9</td><td>6.2</td><td>9.2</td><td>125</td></tr>
</table>

In general, the subsidence rates derived by three methods shown in Table 2, cannot be compared directly since it has quite different temporal and spatial coverage. In this Table 2, the subsidence rates from GPS surveys are the average GPS-derived subsidence rates from 2000 to 2010, while the subsidence rates from InSAR are the average rates from 2006 to 2010, and the subsidence rates from geometric-historic method are observed in 2012. Moreover, location of GPS stations and the geometric-historic measurements are mostly about several hundred meters apart. The InSAR derived subsidence rates are estimated from the final InSAR deformation image in Bandung basin at the coordinates of geometric-historic measurements. Considering the spatial resolution of InSAR images, and also the accuracy of geometric-historic and InSAR methods, then differences shown in Table 2 can be understood.

Moreover, different subsidence rates obtained by the three methods shown in Table 2, in part suggests the existence of local subsidence spectrum of land subsidence phenomena in Bandung basin on top of the regional subsidence spectrum. This local spectrum of subsidence can be caused by different mechanisms of subsidence (*Abidin et al.* 2008b; 2009; 2012a).

5. CLOSING REMARKS

In general nowadays, land subsidence characteristics in urban areas of Indonesia are estimated mainly using geodetic measurement techniques such as Leveling surveys, GPS surveys, InSAR and Microgravity surveys. Each method has its own strengths and limitations, and therefore should preferably used in complimentary manner. Geometric-historic method which recently being used, has its own strengths. It can estimate the subsidence rates from only a single measurement epoch, and it can be used at location which are not accessible by other geodetic measurement techniques. The measurement cost is also relatively much cheaper than other geodetic technique.

However, the geometric-historic method has also potential weaknesses. It has strong subjectivity nature, since the quality of subsidence information derived from geometric-historic will strongly depend on how accurate the vertical displacement and the time period can be estimated from field measurement and historical (documented) and interview data by the field surveyors. Different field surveyor, which has different geometrical insight into the impacts of land subsidence in the field, and has different communication skill in interviewing peoples; can lead to different estimated subsidence rates at the same location.

In studying land subsidence in urban areas of Indonesia (i.e. Jakarta, Bandung and Semarang), the geometric-historic method has been implemented together with other geodetic measurement techniques. In the case of Semarang, the differences between subsidence rates derived by the geometric-historic and GPS surveys methods are about 1-2 cm/year or less. In the case of Bandung however, the differences with those derived from GPS Surveys and InSAR results were found to be larger than Semarang case. In future studies, more investigation will be performed to investigate the accuracy of subsidence rates derived by geometric-historic method at various measurement condition.

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BIOGRAPHICAL NOTES

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