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LandsubsidenceofJakarta(Indonesia)anditsr elationwithurbandevelopment

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Abstract;Jakarta is the capital city of Indonesia with a population of about 9.6 millionpeople,inhabitinganareaofabout660square-km.Inthelastthreedecades,urbandevelopment of Jakarta has grown very rapidly in the sectors of industry, trade, trans-portation, real estate, and many others. This exponentially increased urban developmentintroduces several environmental problems. Land subsidence is one of them. The resultedland subsidence will also then affect the urban development plan and process. It has beenreported for many years that several places in Jakarta are subsiding at different rates. Theleveling surveys, GPS survey methods, and InSAR measurements have been used to studyland subsidence in Jakarta, over the period of 1982–2010. In general, it was found that theland subsidence exhibits spatial and temporal variations, with the rates of about 1–15 cm/year. A few locations can have the subsidence rates up to about 20–28 cm/year. There arefour different types of land subsidence that can be expected to occur in the Jakarta basin,namely: subsidence due to groundwater extraction, subsidence induced by the load ofconstructions (i.e., settlement of high compressibility soil), subsidence caused by naturalconsolidation of alluvial soil, and tectonic subsidence. It was found that the spatial andtemporalvariationsoflandsubsidencedependonthecorrespondingvariationsofgroundwatere xtraction,coupledwiththecharacteristicsofsedimentarylayersandbuildingloads above it. In general, there is strong relation between land subsidence and urbandevelopmentactivitiesinJakarta.

Keywords Jakarta·Landsubsidence·Urbandevelopment·Leveling·GPS·InSAR

Introduction

Thecityof Jakartahasapopulationof about9.6millionpeoplein2010withtotalhou seholds of about 2.2 million (BPS 2011), inhabiting an area of about 661.52 km^2.Jakarta is centered at the coordinates of about −6°15^0(latitude) and ?106°50^0(longitude)and located on the lowland of the northern coast of the West Java province, as shown inFig
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1. Region consisting of Jakarta and its surrounding areas of Bogor, Tangerang, andBekasiareusuallytermedJakartaMetropolitanRegion(JMR),coveringanareaofapproximately7,500km^{2}withtotalpopulationof 27.9millionpeoplein2010. Theareaisrelativelyflat,withthetopographicalslopesrangingbetween0
northern and central parts and between 0° and 5° in the southern part. The southernmostarea of Jakarta has an altitude of about 50 m above mean sea level (MSL). Regionallyspeaking,Jakartaisalowlandareawhichhasfivemainlandforms,namely(RimbamanandSuparan1999; Sampurno2001) : (1) volcanic alluvial fan landforms, which are located inthe southern part; (2) landforms of marine-origin, which are found in the northern partadjacenttothecoastline;(3)beach ridgelandforms,whicharelocatedinthenorthwestandnortheast parts; (4) swamp and mangrove-swamp landforms, which are encountered in thecoastal fringe; and (5) former river channels, which run perpendicular to the coastline. Itshould also be noted that there are about 13 natural and artificial rivers flowing throughJakarta, of which the main rivers, such as Ciliwung, Sunter, Pesanggrahan, Grogol, andtheirtributaries,formthemaindrainagesystemofJakarta.

In the last three decades, urban development of Jakarta and its surrounding areas hasgrown very rapidly in the sectors of industry, trade, transportation, real estate, and manyothers. This exponentially increased urban development introduces several environmentalproblems.Accordingto(FirmanandDharmapatni1994),thisrapidurban developmenthascaused several negative externalities, namely : (1) extensive conversion of prime agri-cultural areas into residential and industrial areas, (2) significant disturbance to mainecologicalfunctionoftheuplandofJakartaareaasawaterrechargeareaforJakartacity, (3) increase in groundwater extraction due to development of industrial activities and thehigh population increase, (4) high concentrations of BOD (Biochemical Oxygen Demand)andCOD(ChemicalOxygenDemand)inmostoftheriversflowingthroughtheJakarta

area as a result of domestic, agricultural, and industrial waste disposal, (5) solid wastedisposal is now felt as a pressing problem, and (6) the air pollution in Jakarta city hasreached a critical point reflected in more evident acid rain. The first three negative impactswill contribute to land subsidence phenomena in several places in Jakarta. The resultedlandsubsidencewillalsothenaffecttheurbandevelopmentplanandprocess.

Land subsidence resulted as side effects of urban development have also been reportedfor several cities, such as Bangkok (Phien-wej 2006), Calcutta (Chatterjeea et al. 2006),Taipei (Chen et al. 2007), Shanghai (Xue et al. 2005), Semarang (Marfai and King 2007;Abidin et al. 2010b), and Bandung (Abidin et al. 2008a). This paper presents and discussesthe characteristics of land subsidence in Jakarta as observed by the geodetics methods (i.e.,levelingsurveys, GPSsurvey methods,andInSARmeasurements)anditsrelationtourbandevelopmentactivitiesinJakarta.

MeasurementsoflandsubsidenceinJakarta

Land subsidence is not a new phenomenon for Jakarta, the capital city of Indonesia. It hasbeen reported for many years that several places in Jakarta are subsiding at different rates(Murdohardono and Tirtomihardjo1993; Murdohardono and Sudarsono1998; Rajiyo-wiryono1999). The impact of land subsidence in Jakarta could be seen in several forms,such as cracking of permanent constructions and roads, changes in river canal and drainflow systems, wider expansion of (inland and coastal) flooding areas, malfunction ofdrainagesystem,andincreasedinlandsea water.

Based on several studies (Murdohardono and Sudarsono1998; Rismianto and Mak1993; Harsolumakso2001; Hutasoit2001), there are four different types of land subsi-dence that can be expected to occur in the Jakarta basin, namely: subsidence due togroundwaterextraction,subsidenceinducedbytheloadofconstructions(i.e.,settlementofhighcompressibilitysoil),subsidencecausedbynaturalconsolidationofalluviumsoil, andgeotectonicsubsidence.Thefirstthreeare thoughttobethe dominanttypesof landsubsidenceinJakartabasin.

In the case of Jakarta, the comprehensive information on the characteristics of landsubsidence is important for several tasks, such as spatial-based groundwater extractionregulation, effective control of flood and seawater intrusion, conservation of environment,design and construction of infrastructures, and spatial development planning. Consideringthe importance of land subsidence information for supporting the development activities inJakartaarea,monitoringandstudyingthecharacteristicsofsubsidencephenomenabecomenecessary. Since 1982, land subsidence in several places of Jakarta has been measuredusing three geodetic techniques, e.g., leveling surveys, GPS surveys, and InSAR technique(Abidin2005; Abidin et al. 2001, 2004, 2008b). The prediction of ground subsidence,based on certain models incorporating geological and hydrological parameters of Jakarta,has also been investigated (Murdohardono and Tirtomihardjo1993; Yong et al. 1995;Purnomoetal.1999).

The first reliable information about subsidence in Jakarta came from results of differ-ential leveling surveys(Abidin et al.2001). The systematic leveling surveys coveringmuch of the Jakarta area were conducted in 1978, 1982, 1991, 1993, and 1997. Except forthe last survey, which was performed by the Local Mines Agency of Jakarta, the levelingsurveys were done by the Local Surveying and Mapping Agency of Jakarta. The levelingsurveys were done using Wild N3, Zeiss Ni002, and Wild NAK precise leveling instru-ments.Eachlevelinglinewasmeasuredindouble-standing(double-run)mode,andeach

leveling session was measured forward and backward to provide survey closure and toverify accuracy (NGS 2011). The leveling line for each session is about 1 km in length.The tolerance for the difference between the forward and backward height-differencemeasurementsissettobe4HDmm ,whereDisthelengthoflevelinglineinkm.

After applying quality assurance criteria related to the standards and requirements forgeodetic leveling (NGS 2011), only three surveys were considered sufficiently accurate forinvestigating the land subsidence in Jakarta; those conducted in 1982, 1991, and 1997.Moreover, only the results from specific leveling points in the network, which are con-sidered the most reliable, are used for investigating land subsidence. In this case, repeat-abilityoftheheightsobtainedfromdifferentsurveysanddifferentloopsandstabilityofthe monument with respect to its local environment are used as the main criteria for selectingthe points. The magnitude of land subsidence was estimated using 45 selected points fromthelevelingnetworksof1982,1991,and 1997(seeFig.2).

Besides using leveling surveys, land subsidence in Jakarta has also been studied usingGPS survey methods (Leick2003). The GPS-based land-subsidence study has been con-ducted by the Geodesy Research Division of ITB since December 1997. Up to now, 13GPSsurveyshavebeenconducted,namelyon:December24–26,1997,June29–30,1999, May31–June3,2000,June14–19,2001,October26–31,2001,July2–7,2002,December 21–26,2002,September21–25,2005,July10–14,2006,September3–

7,2007,August 22–31,2008,July15–20,2009,andMay9–21,2010.

TheconfigurationofthisGPSmonitoringnetworkisshowninFig.3.Thesesurveysdidnot always occupy the same stations. The first survey started with 13 stations, and thenetwork then expanded subsequently to 27 stations in 2008, 50 stations in 2009, and 65stations in 2010. At certain observation period, some stations could not be observed due tothe destruction of monuments, or severe signal obstruction caused by growing trees and/ornew construction. Station BAKO is the southernmost point in the network and is also theIndonesianzeroordergeodeticpoint.Itisusedasthereferencepoint.Inthiscase,the

relative ellipsoidal heights of all stations are determined relative to BAKO station. BAKOisanIGSstation,operatedbyBAKOSURTANALwhichistheIndonesianacronymfortheNationalCoordinatingAgencyforSurveyandMappingofIndonesia.

TheGPSsurveysexclusivelyuseddual-frequencygeodetic-typeGPSreceivers.ThelengthofsurveyingsessionswasingeneralbetweenPand11h.Thedatawerecollected

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witha30sintervalusinganelevationmaskof15.Thedatawereprocessedusingthe software Bernese 4.2 and 5.0 (Beutler et al. 2001, 2007). Since we are mostly interestedwiththe relativeheightswithrespecttoastablepoint,theradialprocessingmodewasusedinsteadofnetworkadjustmentmode.

Considering the length of the baselines of 40–50 km, a precise ephemeris was usedinstead of the broadcast ephemeris. The effects of tropospheric and ionospheric biases aremainly reduced by the differencing process and the use of dual-frequency observations.The residual tropospheric bias parameters for individual stations are estimated to furtherreduce the tropospheric effects. In the case of the residual ionospheric delay reduction, alocal ionospheric modeling is implemented. The algorithms for the tropospheric parameterestimation and local ionospheric modeling can be found in Beutler et al. (2001, 2007). Inprocessing baselines, most of the cycle ambiguities of the phase observations were suc-cessfully resolved. The estimated standard deviations of GPS-derived relative ellipsoidalheightsfromallsurveyswereingeneralbetterthan1cm(Abidinetal.2008b).

Since 2004, subsidence phenomena in Jakarta also have been studied using InSAR(InterferometricSynthetic ApertureRadar)techniques(Schreier1993; MassonnetandFeigl1998). The initial results are provided in Abidin et al. (2004). Recently, InSARtechniques were applied to study land subsidence in the Jakarta area using data from theALOS/PALSAR satellite, which was launched in January 2006 as a successor of JERS-1/SAR. The SAR data observed during June 2006 and February 2007 were used. They wereacquiredinFineBeamSinglePolarizationmode(HHpolarization)withoff-nadirangleof 41.5degrees.InSARprocessinghasbeenperformedusingLevel1.1products(SLC:SingleLookComplex)distributedtothepublicby ERSDAC(EarthRemoteSensingDataAnalysis Center) in Japan. The processing software for InSAR was developed by Deguchi(2005)andDeguchietal.(2006).

CharacteristicsoflandsubsidenceinJakarta

The results obtained from leveling surveys, GPS surveys, and InSAR technique over theperiodbetween1982and2010showthatlandsubsidenceinJakartahasspatialandtemporalvariations.ThisindicatesthatthesourcesoflandsubsidenceinJakartaalsodifferspatially.Land subsidence only affected several regions of Jakarta, and in general, the observed sub-sidence rates are about 1–15cm/year, and can be up to 20–28cm/year at certain location andcertainperiod.Thesummaryof subsidencerates inJakartaisgiveninTable1. From leveling surveys, it was found that the maximum subsidence during the period of1982–1991isabout80cm,whilefortheperiodof199

1–97isabout160cm(seeFig.4).In general, the subsidence rates in Jakarta area during this period are about 1–5 cm/yearand can reach 25 cm/year at several locations. During the period between 1982 and 1991,the maximum rate of subsidence is about 9 cm/year, while during the period between 1991and 1997 it is about 25 cm/year. More comprehensive results on leveling-based subsidenceinJakartacanbeseeninAbidineta l.(2001).

In general, the GPS observed subsidence rates during the period between December1997 and May 2010 are about 1–28 cm/year. Examples of GPS-derived land subsidence atseveral observing stations are shown in Figs. 5 and 6.On Fig.5, the first measurement ateach point established the baseline elevation for that site and, therefore, is shown as zeroelevation change. The different color codes for the individual bars in these figures indicatethat they were estimated from different GPS surveys. In about 10 years, i.e., Dec. 1997 toSept.2007,theaccumulatedsubsidence atseveralGPSstationscanreachabout80–90cm.

AmorecomprehensivereviewofGPS-derivedlandsubsidenceinJakartaduringthe periodof 1997–2005 can be seen in Abidin et al. (2008a). The subsidence rates during the periodsof2007–2008,2008–2009,and2009–2010areshowninFig.6,withthemaximumratesofabout−28,−14,and−16cm/year,respectively.

Example of InSAR-derived land subsidence in northern part of Jakarta, over the periodof June 2006 to February 2007, is shown in Fig. 7. In this figure, subsidence is calculatedby multiplying the number of color fringes by 11.8 cm. This figure shows that subsidencealong the coastal zone of Jakarta has a spatial variation. After correlation with GPS results,it was found that the maximum InSAR-derived subsidence rates for the 8 month periodbetween InSAR measurements reached about 12 cm/year. This subsidence rate is comparablewiththerateobservedbytheGPSandl evelingsurveysinthesameperiod.

Please note in Fig. 7, that of the area showing the largest land subsidence in this(2006–2007)periodislocatedinPantaiMutiarahousingcomplex.TheGPSstationMUTIislocate d in this area and, as shown in previous Fig. 5, this station also experienced largesubsidence,i.e.,about80–90cmduringtheperiodofDecember1997an dSeptember2007.

Urbandevelopmentandlandsubsidence

Land subsidence in Jakarta can be caused by four factors, namely: excessive groundwaterextraction, load of buildings and constructions, natural consolidation of alluvium soil, andtectonic activities. Up to now, there is no information yet about the contribution of each factoronthesubsidenceateachlocationandth eirspatial(contribution)variation.IncaseofJ akarta,tectonic activities seem to be the least dominant factor, while excessive groundwaterextractionisconsideredtobeon eofdominantfactor.Tectoniccauseswereex cludedinthiscase, since at this time, there is no strong evidence on the existence of active (normal or thrust)faultsinJakartaregion(Harsolumaks o2001).Thefirstthreefactorswillhavecloser elationwithurbandevelopment activitiesinJakartaand itssurroundingareas.

Increaseinpopulationandbuilt-upareas

Urban development in Jakarta is going-on rapidly. According to (Firman and Dharmapatni1994),Jakartahasbeenthemos tattractiveareainIndonesiafordomesticand direct foreign investment because of its better infrastructure, high concentration and access tomass markets, pool of skilled labor and entrepreneurs, and high access to the decisionmakers. The economic activities in the region have grown very

rapidly, especially inindustry, trade, transportation, real estate, and many other sectors and have also spilledover into the adjacent areas of Jakarta Metropolitan Region (JMR), such as Bogor, Tan-gerang, Depok, and Bekasi. Nowadays, JMR is the largest concentration of urban popu-lation and economic activities in Indonesia, consisting of about 80% urban population and20% rural population (Firman2004). It then increases the urbanization rates into Jakartaandsurroundingareasandpopulation ofJakartagrowthrapidly.Consequently,coverageofthe built-up areas is increased and the green areas are decreased. Built-up areas of Jakartain2008coverabout90%oftheregion.
According to (Lo Fu-chen and Yue-man Yeung [Eds] 1995), in 1948, the population ofJakartawasabout2million,withabuilt-upareaof20,000ha(about30%),includingKebayoranBaru, a new town in the south. In 1965, the population of Jakarta was about 4million, with a built-up area of 35,000 ha (about 53%). By 1980, Jakarta has a populationof 6.5 million, and it was by this time that the influence of the city on the region (ratherthansimplyonitsfringes)wasclearly demonstrated.In2010,thepopulationofJakartaandJMR has already reached 9.6 and 27.9 millions, respectively. The population growth ofJakartaandJMRisshowninTable2.
The increase in population and urban development activities in Jakarta lead to increasein built-up areas and decrease in green areas. New residential areas, industries, condo-miniums,malls,hotels,commercials,andofficebuildingshaveproliferatedinJakartain

the last three decades. In 2006, there are already 306 hotels, in which 135 are star (clas-sified) hotels, and 1955 large and medium manufacturing companies in Jakarta (BPSJakarta 2007). In 2004, Jakarta already had 73 large shopping malls, besides some 116department stores, 125 super markets and 151 traditional markets (Steinberg 2007). TheareasofshoppingmallsinJakartahavesignificantlyincreased from1.4millionm^{2}in2000to2.4millionm^{2}in 2005(Firman2009). Unfortunately,thesedevelopmentsmostlyoccupiedtheavailablegreenareasinJakarta.In 1965, the green areas made up more than 35 percent of the Jakarta’s area and currentlyaccount for only 9.3 percent of the area (Rukmana2008). Several new towns have alsobeendevelopedalongtheperimeterofJakartaanditssurroundingareaswhichalsoincrease the coverage of built-up areas in the region. Figure 8 shows the sharp increase incoverageofbuilt-upareasinJakartasince1972–2005.
This increase in built-up areas directly affects the water recharge areas and recharge-ability of withdrawn groundwater in Jakarta and its surrounding areas. Coupled with theincrease consumption of groundwater due to increase in population and economic andindustrial activities, the (ground and surface) water system in Jakarta and its surroundingareas are severely affected. In turn, it will contribute to occurrence of land subsidencephenomenainseverallocationsinsideJakarta,asdepictedbyFig.9.

Excessiveuseofgroundwater

The population growth and increase in economic activities in Jakarta and its surroundingregion lead to the increase in water need. Unfortunately, about 64% of water need inJakarta is fulfilled by groundwater extraction (Ali 2011), either because piped treatedsurface water supplies were inadequate or because it was substantially cheaper to do so(Colbran2009).Forthesamereason,thisoverdischargingofgroundwaterwoulddeepen thepiezometric water level inside the aquifers and in turn would cause land subsidenceaboveit.
Three aquifers are recognized within the 250 m thick sequence of Quaternary sedimentoftheJakartabasin,namely:theUpperAquifer,anunconfinedaquifer,occursat

adepthofless than 40 m; the Middle Aquifer, a confined aquifer, occurs at a depth between 40 and140m;andtheLowerAquifer,aconfined aquifer,occursatadepthbetween140and250 m (Soetrisno et al. 1997; Hadipurwo1999). The geologic materials confining theseaquifersaresiltandclay.Insidethoseaquifers,thegroundwatergenerallyflowsfrom southto the north (Lubis et al. 2008). Below a depth of 250 m, an aquifer in the Tertiarysediments also has been identified. But according to Murdohardono and Tirtomihardjo(1993),itislessproductiveanditswaterqualityisrelativelypoor.

ThegroundwaterextractioninJakartacouldbecategorizedintoshallow(<40m)and deep(>40m) extraction. Shallow extraction isthroughdugwellsordrivenwells, operated withbuckets,handpumps,orsmallelectrical pumps;whereasthedeepextractionismostly from drilled wells. Shallow extraction is mostly done by the population. It is well spreadover the area, but its extraction rate per well is relatively low. Deep extraction is usuallyconducted by industry. It is usually more concentrated and has a relatively high extractionrate per well. The number of registered drilled wells in Jakarta was about 3,700 wells in2007 (see Fig. 10). Based on the studies done by Murdohardono and Tirtomihardjo (1993),from the sample of 197 drilled wells in Jakarta, out of 2,800 registered drilled wells at thattime, 156 wells (79%) are extracting groundwater from depths between 40 and 140 m, and41wells(21%)areextractingfromdepths between140and250m.

The registered groundwater extraction in Jakarta varies from just 3 Qabs (million m^3) in1,879 up to maximum of 34 Qabs in 1994, down to 17 Qabs in 1998 after the Indonesianeconomic crisis of 1997, and then go up again to about 22 Qabs in 2007 (see Fig. 10). Itshouldbepointedoutherethatthesenumbersmaynotreflecttherealgroundwaterextraction in Jakarta basin. According to Soetrisno et al. (1997), the unregistered deepgroundwater extraction in Jakarta can be as high as 50% or even more. This excessivegroundwaterpumpingwillusually leadtothedeepeningofthepiezometricwater level

inside the middle and lower aquifers. According to Soetrisno et al. (1997), the piezometriclevel in North Jakarta has changed from 12.5 m above sea level in 1910 to about sea levelin1970sandthendeepenedsignificantlyto30–50mbelowsealevelin1990s.

The subsidence rate is closely related to the rate of piezometric water level (head)deepening in the middle and lower aquifers. In the case of Jakarta, the increases in bothpopulation and industry, which require a lot of groundwater, could explain the abovedecliningtrendofpiezometricheads,asshowninFig.11.

The correlation between land subsidence and excessive groundwater taking in Jakartacan be illustrated using the subsidence results obtained from leveling surveys.

PreviousFig.4showstheobservedlandsubsidenceduringtheperiodof1982–1991and1991–1997. If we compare Figs.11 and 4, it can be realized that the cones of piezometricleveldepressionsinsidethemiddleandloweraquifersmoreorlesscoincide withtheconesof largest land subsidence measured by the leveling. It should also be noted here that inthose areas of subsidence cones, due to their high soil compressibility, the situation couldbeworsewiththesettlementcausedbytheloadofconstructions.

The groundwater level inside the middle and lower aquifers at several locations inJakartacontinuetodecline.Table3showsthatthegroundwaterlevelsaredecreasingwith

rates of about 0.1–1.9 m/year over the period of 2002–2007. In comparison with GPS-derived subsidences, it can be seen that the large subsidences are usually associated withthe relatively high rates of groundwater level change rates. However, the relation betweenland subsidence and localized groundwater level decrease will not always be a direct andsimple relation. A more detail explanation on GPS-derived subsidence and its relation withgroundwaterextractionisgiveninAbidinetal.(2010a).

It should be realized, however, that in the shorter time scale, the groundwater levelchangesinsidetheJakartaaquifersarequitedynamic(Abidinetal.2010a).Thesegroundwater levels can go up and down up from several decimeters to a few meters in ayear. The effect of this short-term variation in groundwater level inside the aquifers on thelong-term subsidence phenomena in the Jakarta area and its spatial variations are not yetfullyunderstood.Moreresearchisneeded tostudyandclarifythismatter.

Coastaldevelopment

Coastal area of Jakarta has also experienced extensive urban development. Many estab-lishments take place in this coastal region, such as sea port, coastal resort, golf course,residentialareas,industries,condominiums,malls,hotels,andcommercialandofficebuildings(seeFig. 12).Someareashavealsobeenreclaimedtoaccommodatemorecoastaldevelopmentinitiatives.Itshouldbepointedoutthattheobservedlandsubsidencesalong the coastal areas of Jakarta are relatively have larger rates, as indicated in previousFigs.4to7.

GPS-derivedsubsidenceratesforthecoastalstationofMUBA, MUTI, andPIKA (shown in Fig. 12) in the period of 2008–2009 are −14, −10, and −11 cm/year,respectively.Intheperiodof2007–2008,theratesareevenlarger,i.e.,−28,−15,and −18 cm/year, respectively. In the latest observation period of 2009−2010, the rates are −15, −8, and −7 cm/year, respectively. Relatively large subsidence in the coastal areas willcertainlyaffectthecoastaldevelopment ofJakarta.

Considering the sea-level rise phenomena, coastal subsidence in Jakarta will certainlyaffect coastal development in Jakarta (Abidin et al. 2010a). Considering the relatively flatnature (i.e., 0–2 m above MSL) of most coastal areas of Jakarta, this combined effect ofland subsidence and sea-level rise will certainly be have disastrous consequences forhabitation, industry, and fresh groundwater supplies from coastal aquifers. During hightides, tidal flooding is already affecting some of these coastal areas, as shown in Fig. 13.The extent and magnitude of subsidence-related flooding will worsen withthe likelycontinuation of sea-level rise along the coastal area of Jakarta, which has the rate of about4–5mm/year(Nurmauliaetal.2010).

Impactsofsubsidencetourbandevelopment

Impacts caused by land subsidence to urban development in Jakarta can be seen in severalforms. The differential subsidence nature in Jakarta basin may introduce the cracking anddamage in buildings and infrastructure and may change the flow pattern of surface water.Subsidence may also enlarge the (tidal) flooding inundation areas, and in general willdeteriorate their environmental quality. Subsidence along several coastal areas of Jakartaalso makes themmore vulnerabletoward sea-levelrisephenomena. Figure 14showsseveralindicationsoflandsubsidencephenomenainJakarta.

In case of Jakarta, which is actually prone toward flooding, subsidence phenomena hasto be fully understood for flood management system. Land subsidence will decrease ele-vation of the dikes and drainage system. It will reduce the function of city drainage systemin the subsidence affected areas and may introduce flooding during the rainy season.During the period between 1993 and 2007, at least there are four big floods in Jakarta,namelyonJanuary9–10,1993,February1996,January26–February1,2002,andFebruary

Closingremarks

The results obtained from leveling

surveys, GPS surveys, and InSAR technique over theperiod between1982 and 2010 showthatland subsidence in Jakarta has spatial andtemporal variations. In the areas affected by land subsidence, in general, the observedsubsideneratesareabout1–15 cm/yearandcanbeupto20–28 cm/yearatcertainlocationandcertainperiod.Thereisastrongindicationthatlandsubsidencein Jakartaareais governed by the excessive groundwater extraction from the middle and lower aquifers,besides also by building/construction load and natural consolidation of sedimentary layers.Theexcessivegroundwaterextractioncausestherapiddecreaseingroundwaterlevelinside the aquifers and in turn causes the land subsidence above it. However, the relationbetween land subsidence and groundwater level decrease inside the aquifers in certainlocationwillnotalwaysbeadirectandsimplerelation.

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