Implementation of GPS CORS for Cadastral Survey and Mapping in Indonesia: Status, Constraints and Opportunities

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Key words: GPS, CORS, Indonesia, Cadastral, Survey, Mapping

SUMMARY

Since 2009, BPN GPS CORS has been tested for supporting cadastral survey and mapping in Indonesia, although still just limited to certain areas in Java and Bali islands. The main aim of this GPS CORS implementation is to speed up the land registration process in Indonesia; in which about 55% land parcels still to be certificated (e.g. about 48 million parcels), and about 90% area still to be mapped for cadastral purposes (e.g. about 83 million ha). At present there are 75 BPN GPS CORS stations have been established, mostly in Java and Bali,

In establishing, operating and maintaining the good and reliable BPN GPS CORS that can serve cadastral survey and mapping all over Indonesia, there are several challenges and limitations that have to be properly taken into consideration mainly related to: (1) availability and reliability of communication link system, (2) establishment of reliable GPS CORS data processing and management at BPN and related land offices, (3) spatial and temporal variation in achievable accuracy of real-time coordinates, and (4) relatively still insufficient number of dedicated and professional GPS CORS surveyors at BPN and all district land offices.

Future and opportunities of the BPN GPS CORS network are also very promising. Besides for supporting cadastral survey and mapping, and other positioning related activities; it can also support the national programs, such as the Masterplan of Acceleration and Expansion of Indonesia Economic Development 2011-2025 program and also the natural hazard mitigation related programs and activities.

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1. INTRODUCTION

Indonesia is an archipelago consisting of about 17,500 island, with the size of about 5000 km (east-west) by 2500 km (north-south). It has a land areas of about 188,987,000 ha, consisting of about 96,056,000 ha of forest areas and 92,931,000 of non-forest areas; with the population of about 238 millions in 2010. If each family is assumed to consist of 3.4 persons, and each family in average has 1.25 land parcels, then it can be stimated that there are about 87 millions land parcels in 2010 (see Table 1). In 2008, the registered number of land parcels that have payed the fiscal tax is about 85.8 million parcels.

Table 1. Status of land parcel registration in Indonesia

Region	Population (2010)	Estimated number of land parcel (2010)	Number of certificated land parcel (2008)	% of certificated parcel (2008)
Sumatera	50,630,931	18,614,313	6,937,884	37.3
Java	136,610,590	50,224,482	23,916,371	47.6
Bali & Nusa Tenggara	13,074,796	4,806,910	2,491,899	51.8
Kalimantan	13,787,831	5,069,056	2,662,182	52.5
Sulawesi	17,371,782	6,386,685	2,553,690	40.0
Maluku & Papua	6,165,396	2,266,690	461,465	20.4
Total	**237,641,326**	**87,368,135**	**39,023,491**	**44.7**

Land registration in Indonesia is still far from completion. Since a more systematic land registration started in 1960, only about 39 million parcels have been certificated up to 2008. It means in about 48 years only about 45% land parcels that have been certificated. In order to speed up this land registration process, several involved mechanisms have to be improved and modernized, which one of them is related to cadastral survey and mapping method. In this case, the National Land Agency of Indonesia (BPN) should implement as soon as possible the GPS CORS system that can fully support the survey and mapping all over Indonesian region. In order to gain maximal benefit, the synergism of this BPN GPS CORS system with the Geospatial Information Agency of Indonesia (BIG) GPS CORS system (*Abidin et al.,* 2010) should also be realized, both in conceptual and operational domains. The existence of good and reliable BPN GPS CORS network covering the Indonesian region will not just usefull for cadastral survey and mapping, but also for other types of land positioning, surveying and mapping activities.

2. THE GPS CORS NETWORKS IN INDONESIA

At present there a few GPS CORS networks operating in Indonesia. They are established and operated by two main national agencies, namely the Geospatial Information Agency of Indonesia (Badan Informasi Geospasial, BIG, formerly known as Bakosurtanal); and the National Land Agency (Badan Pertanahan Nasional, BPN). Other institution such as Indonesian Institute of Sciences (LIPI), GITEWS (German Indonesian Tsunami Early Warning System), private sectors and a few universities (ITB, UGM and ITS) have also established GPS CORS networks. At present, at least there are more than 230 GPS CORS stations in Indonesia, consisted of 101 BIG, 75 BPN, 18 GITEWS, 32 LIPI SUGAR (Sumatera GPS Array), 5 ITB, 1 UGM and 1 ITS CORS stations. Number of GPS CORS stations established by the private sectors in Indonesia are relatively unknown, but it can be expected it will not more than 10-20 stations.

In principle, the national GPS CORS network of Indonesia, is officially the one that is established by BIG [*Subarya,* 2004; *Matindas and Subarya,* 2009; *Abidin et al.,* 2010]. This network is usually termed as the Indonesian Permanent GPS Station Network (IPGSN); and its primary purpose is to maintain an accurate and precise geodetic reference frame over Indonesian region, and also to support a wide range of scientific and practical applications such as geodynamics and deformation monitoring, meteorological and ionospheric studies, sea level monitoring, intelligent transportation systems, and real-time based surveying and mapping applications. The establishment of this BIG GPS CORS network was initiated in 1996 which is started with three stations in Cibinong (West Java), Sampali Medan (North Sumatra) and Parepare (South Sulawesi). The network was afterward systematically strengthened with more stations, and after the Sumatra-Andaman earthquake and tsunami of 26 December 2004, the IPGSN network was rapidly developed. This rapid development is part of the development of the Indonesian Tsunami Early Warning System (InaTEWS). The GITEWS program also added similar quality of GPS CORS stations to strengthen the BIG GPS CORS network. The distribution of existing 101 BIG Stations and 18 GITEWS stations at the present time is shown in Figure 1.

In order to speed up the land administration process in Indonesia, BPN has also started to establish GPS CORS, consisting of Class-A and Class-B type stations [*Adiyanto et al.,* 2009]. All of the BPN CORS stations are equipped with dual-frequency geodetic-type GPS receivers. The Class-A type stations are established on the ground and have specification and performance comparable to the IPGSN stations maintained by Bakosurtanal. The Class-B type stations are usually installed on the building, mostly in the land office building in the corresponding areas. At present there are 75 GPS CORS stations have been established, mostly in Java and Bali, as shown in Figure 2.

LIPI, in collaboration with the California Institute of Technology (Caltech) and the Earth Observatory of Singapore (EOS), has also established the SUGAR (Sumatera GPS Array) network, consisting of 32 continuous stations [*Caltech,* 2010; *Natawidjaja,* 2010]. All stations are equipped with the dual-frequency geodetic type receivers, with choke ring antennas and radomes; and record the data with 1 Hz data rate. The data collected by this CORS network has been used to study the deformation related characteristics of large earthquakes in the subduction zones of the Sumatra island [*Abidin et al.,* 2010].

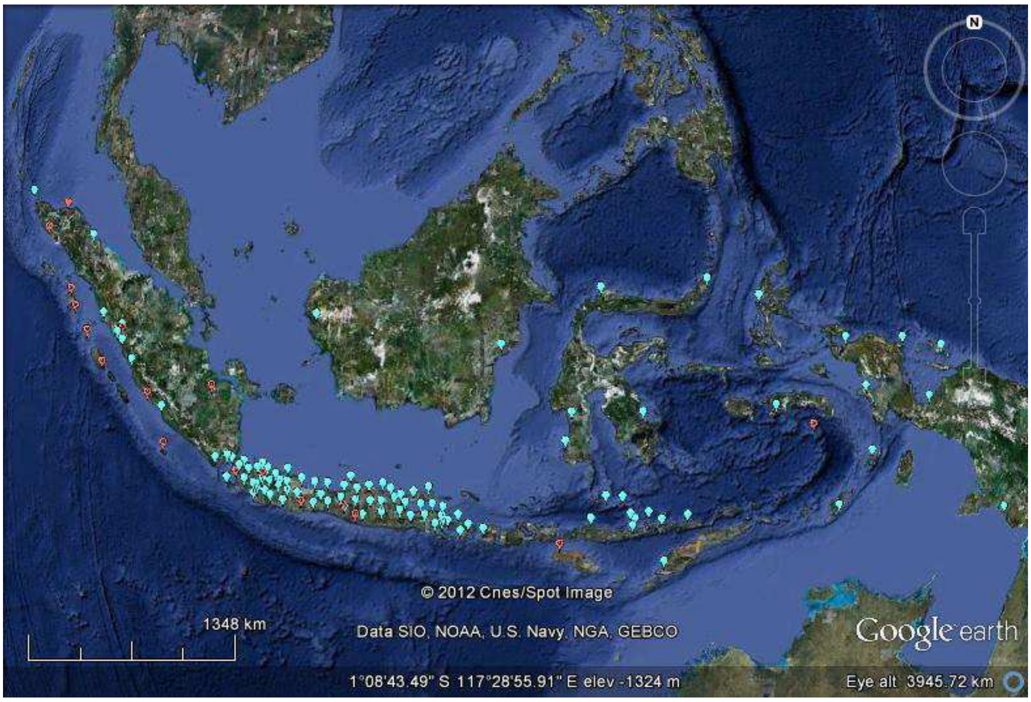

Figure 1. Distribution of GPS CORS stations: 101 BIG Stations plus 18 GITEWS Stations.

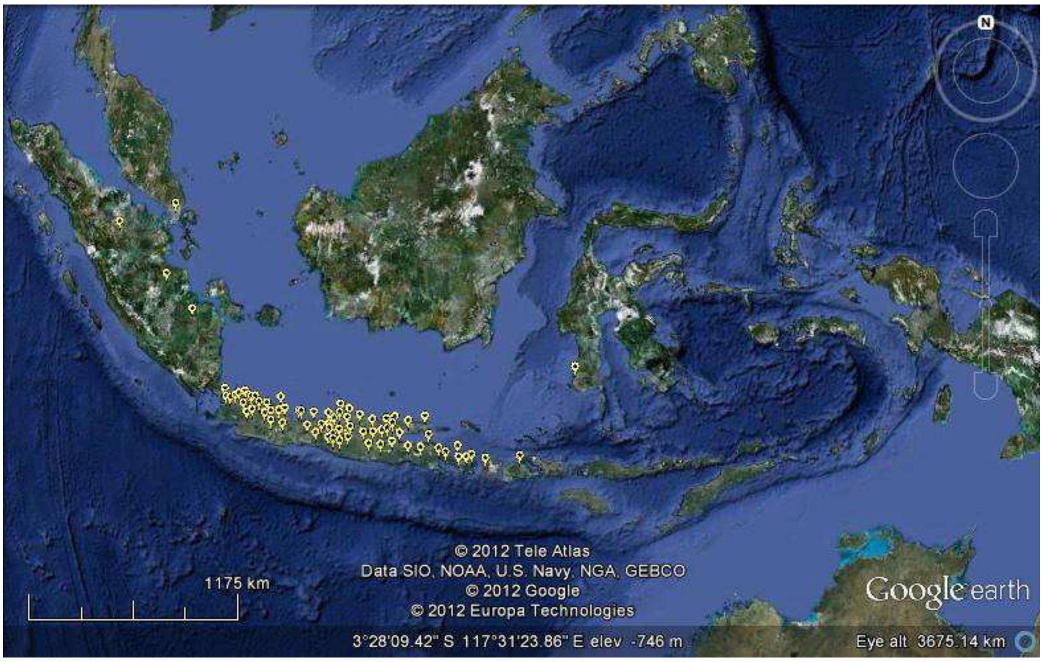

Figure 2. Distribution of GPS CORS stations of 75 BPN Stations.

Several universities, namely Institute of Technology Bandung (ITB) in Bandung, University of Gajah Mada (UGM) in Yogyakarta and Institute of Technology 10 November (ITS) in

Surabaya have also established GPS CORS stations in their campuses [*Sunantyo,* 2009; *Abidin et al.,* 2010]. In this case, the Geodesy Research Division of ITB, in cooperation with GSI Japan, ERI University of Tokyo, and Bakosurtanal, has established 5 GPS CORS stations in West Java region. The main aim of this CORS network is to study the inter-seismic deformation of active faults in West Java, e.g. Cimandiri, Lembang and Baribis faults [*Abidin et al,* 2009; 2010].

Finally it should be emphasized that GPS CORS in Indonesia will be useful for various existing applications in Indonesia and also will create more innovative applications, both in real-time and post-processing modes, as shown in Table 2.

Table 2. Existing and potential utilization and function of GPS CORS, after [*Abidin et al.,* 2010].

Utilization and Function of GPS CORS	
Real-time mode	**Post-processing mode**
Early warning system for various natural hazards in Indonesia.	The coordinate reference frame for various positioning, surveying and mapping applications in Indonesia.
The Network-RTK system for surveying and mapping applications.	The coordinate reference frame for monitoring and studying natural hazard phenomena in Indonesia
The reference stations for supporting various navigation and transportation applications (land, marine, air).	The monitoring network for geodynamics and tectonic studies in Indonesian region.
Integration, checking and validation for various coordination reference systems	Studying and mapping the characteristics of troposphere and ionosphere above Indonesian territory.

3. CADASTRAL SURVEY AND MAPPING IN INDONESIA

Up to present, GPS for cadastral surveying in Indonesia is mainly used for [*Abidin et al.,* 2011]: (1) establishment of the cadastral control network, (2) determination of parcel boundary coordinates, and (3) reconstruction of parcel bounday points. Although GPS CORS are starting to be established, the use of GPS for cadastral survey and mapping in Indonesia is usually implemented in GPS survey static or in a single station GPS RTK modes.

Cadastral survey and mapping in Indonesia is basically started in a more systematic manner since 1960. Up to about 1994, the terrestrial based measurement techniques were generally used for cadastral survey and mapping, and the coordinates of parcel boundaries were given in local coordinate systems of their own. The problems started to surface when the parcel boundaries were plotted in a single cadastral basic map of the area. Many parcels were overlapped between each other and sometimes gaps between parcels were also existed. In turn, this technical problem generated several legal problems which then delayed the whole land administration process in the corresponding areas.

In order to overcome the aforementioned problems, since 1994 GPS static survey method has been used in establishment of the National Cadastral Reference Network (NCRN) [*Abidin et al.,* 1998; 2011]. This network is established and maintained by BPN and aimed to serve all cadastral surveying and mapping activities in Indonesia, and categorized into 2nd, 3rd and 4th order networks based on the accuracy level and spatial spacing of its benchmarks in the field. The spatial spacing for 2nd and 3rd order NCRN bechmarks which are established using GPS survey method are about 10 km and 2 km, respectively. In the case of 4th order NCRN which is established using traversing (polygon) method, spatial spacing of benchmarks vary from about 100 m to 150 m. The coordinates of parcel boundaries are then determined from the 4th order NCRN stations.

In their establishment, the 2nd and 3rd order NCRC is connected directly or indirectly to the 0th and 1st order National Geodetic Reference Networks (NGRN) that is established and maintained by BIG. If it is assumed that NCRN has configuration as mentioned above, then Indonesian region outside forest areas will have about 9,000 and 200,000 points of 2nd and 3rd order NCRN, respectively (see Table 3). Up to 2010, the realization of these 2nd and 3rd order NCRN are about 70% (6,699 points) and 7% (14,085 points), respectively. It will take several decades to complete the NCRN network, especially the 3rd order network. The completion of the 4th order NCRN will then even further delayed, and therefore the land parcel registration process will also be slowdown.

Table 3. The estimated number of 2nd and 3rd order NCRN stations

Region	2nd order	3rd order
Sumatera	2,800	61,511
Java	1,270	25,753
Bali and Nusa Tenggara	473	11,295
Kalimantan	2,075	43,095
Sulawesi	901	17,117
Maluku and Papua	1,900	39,262
Total	**9,419**	**198,033**

In the year 0f 2008, the rate of land parcel certification issuing is already reaching about 3 million certificates per year (see Table 4). Considering that there are still about 48 million parcels left to be certificated, then at least another 18 years since 2008 are needed to complete the whole land registration process, if there no improvement is taken related to cadastral survey and mapping activities. Considering land transactions and land splitting that maybe happening in due course, then even longer time for land registration completion in Indonesia can be expected.

Table 4. Yearly number of issued land parcel certificates in Indonesia (2001-2008)

Year	Sumatera	Java	Kalimantan	Bali & Nusa Tenggara	Sulawesi	Maluku & Papua	Indonesia
2001	234.856	751.709	58.193	121.532	83.343	4.109	1.253.742
2002	273.379	742.518	68.755	148.873	57.749	4.520	1.295.794
2003	256.765	672.509	70.696	121.116	57.322	4.972	1.183.380
2004	202.005	662.294	56.193	143.592	98.036	2.035	1.164.155
2005	185.914	571.201	53.361	54.762	42.345	11.736	919.319
2006	186.736	887.278	89.461	94.688	71.348	16.298	1.345.809
2007	373.544	1.764.063	108.355	239.167	179.932	26.106	2.691.167
2008	654.992	1.779.295	314.246	223.478	48.815	11.595	3.032.421

In order to speed up the whole land registration process in Indonesia, then starting in 2009 BPN has initiated to use GPS CORS for establishing the cadastral control network and determining the parcel boundary coordinates whenever it is possible. Although still in its preparation, testing and initial implementation period, the utilization of GPS CORS for supporting cadastral survey and mapping is foreseen can speed up the whole land registration process in Indonesia.

4. CHALLENGES AND LIMITATIONS

In establishing, operating and maintaining the good and reliable GPS CORS network of BPN that can serve cadastral survey and mapping all over Indonesia, there are several challenges and limitations that have to be properly taken into consideration [*Abidin et al.*, 2011]. These factors have both structural and cultural natures, and can be summarized as in the following.

1. The cadastral survey and mapping in Indonesia should not be supported only by the BPN GPS CORS, but preferably also by other national GPS CORS especially the BIG GPS CORS. The functional synergy of the CORS networks will lead to more effective and efficient cadastral survey and mapping, both in terms of spatial coverage, availability and reliability of the positioning services. Figure 3 shows that by integrating the BIG, BPN and GITEWS CORS networks, basically all land areas of Java, the most populous island in Indonesia, can be covered by the CORS services. However, integrating these CORS networks are quite challenging, especially in terms of financial sharing arrangement and human resources deployment for standardized system operation and maintenance. Technical matters related to the standardized and synchronized data acquisition, data processing, data communication and data archiving system among those CORS networks should also be worked out.

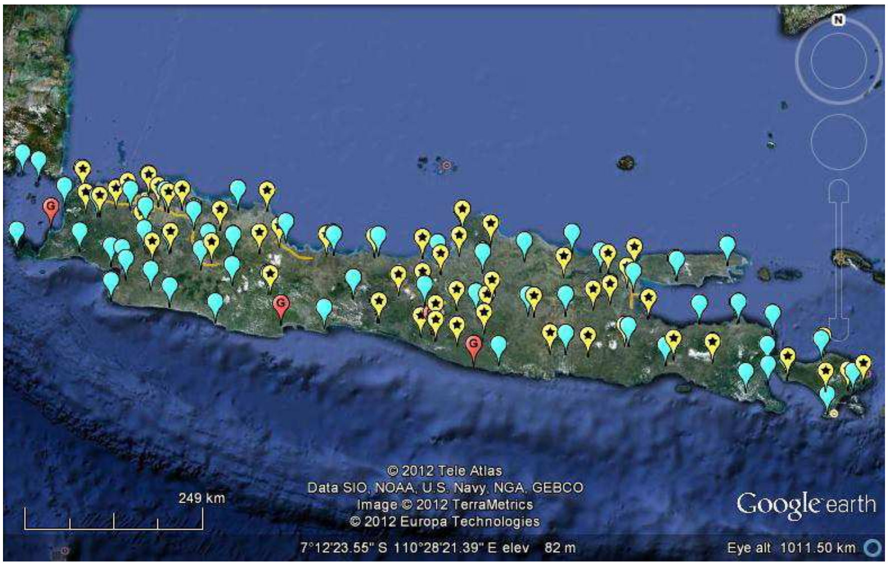

Figure 3. Distribution of GPS CORS stations in Java, consisted of BIG (blue), BPN (yellow) and GITEWS (red) stations.

2. At present, the BPN GPS CORS stations are mostly located in Java island, as shown in Figures 2 and 3. In order to speed up the land administration process in Indonesia, then this network should be established to cover all Indonesian territory outside Java island as soon as possible. Indeed, it will need strong political will and continuous financial support from the Indonesian government, and also it requires good planning and execution process from BPN side.

3. The reliability of the BPN GPS CORS will strongly depend on good and reliable communication links between the continuous GPS stations and its data processing centre. All GPS CORS stations will be most probably located at the district land offices all over Indonesia. Considering the vast area being cover, the archipelagic nature of Indonesia, and relatively high spatial divide in the communication infrastructure inside the Indonesian region, the communication link aspects of the CORS system should be planned and established in an effective and efficient manner. Considering various geographical conditions of Indonesian territory and also existing telecommunication coverage, the data communication of BPN GPS CORS should utilize either GSM (3G, EDGE, HSDPA) , LAN/WAN (Local Area Network/ Wide Area Network) or broadband Internet.

4. In order to have good, reliable and continuous mode of operation, all remote continuous GPS stations will also require proper and continuous maintenance and caring. Each station will therefore need proper resources all year long, e.g. electrical power supply, related hardware and software resources, and human resources for checking and taking care the station site and equipments. The difficulty in operating and maintaining the BPN GPS CORS station in Indonesia will vary and usually getting more difficult when its location getting farther away from Java island and/or from large urban areas. Power supply from solar energy seems to be the best backup choice for relatively remote BPN GPN CORS stations. The financial support for the daily operation and maintenance of GPS CORS stations therefore should always be considered, preferably in the long term basis.

5. Maintenance and operation of the relatively large scale BPN GPS CORS networks in Indonesia, will require also conducive and professional working culture, and good support from dedicated and professional human resources at BPN and all district land offices. This human capital, is not needed just to operate and maintain the whole system, but also to process the collected data and analyze the obtain results for various applications and interests. At present times, the working culture in the government offices are not always compatible and suitable with the working culture needed for maintaining and operating the good and reliable GPS CORS networks. The number of qualified and dedicated persons for maintaining and operating GPS CORS should also be increased and provided with proper reward and remuneration. In this case, outsourcing part of the operational and maintenance activities of BPN GPS CORS network to the private company may also be considered.

6. Since the large scale BPN GPS CORS network covering Indonesian region will require substantial amount of qualified human capital, the related human resource development program should also be systematically planned by BPN and the land offices. In terms of

high learning institutions, at present times in Indonesia there are four state universities (ITB Bandung, UGM Yogyakarta, ITS Surabaya, and Undip Semarang) and three private universities (Itenas Bandung, ITN Malang, University of Pakuan Bogor) that have study programs on surveying, geodesy and/or geomatics engineering. In the context of GPS CORS related capacity building in related institution, those high learning institutions, besides supplying their graduates can also offer various Continuing Education Programs (CEP) for enhancing the competency of human resources belonging to various agencies related to the GPS CORS programs.

7. Since the development of good and reliable national BPN GPS CORS network will absorb a lot of money and efforts, the use of the system is preferably not just only for supporting cadastral surveys and other land administration related activities. Therefore, it should also support other national needs and interests in land and coastal positioning, surveying and mapping activities. Since each application usually will have their own specification on data requirement and management, then the BPN GPS CORS system should be adaptively designed and operated to fully support those various applications. Although it will put more burden and responsibility on BPN, however if this multi-purpose BPN GPS CORS can be realized, its sustainability will not be an issue anymore.

8. In the implementation of GPS CORS for cadastral surveys in Indonesia, especially for parcel boundary determination and reconstruction, the combination with terrestrial measurements is usually required [*Abidin et al.,* 2011]. Typical topography and land coverage around land parcel boundaries in Indonesia, will not always allow for good GPS observation directly at the parcel boundary points (see Figure 4). Significant GPS signal obstructions from buildings and tress can be frequently expected. Therefore, in the implementation of BPN GPS CORS system, the integrated GPS/ETS system will be more effective to be used as the rover unit for the parcel boundary determination and reconstruction, and other cadastral survey activities. In very dense urban environments (e.g. left photo in Figure 4), the use of measuring tapes in trilateration mode sometimes are more effective. In this case, GPS points in the open areas are used as control points for distances measurements using the tapes.

Figure 4. Typical land coverage of urban and rural areas in Indonesia.

9. Due to the heterogenity in data communication quality and coverage, and also due to the wide spectrum of topography and land coverage in Indonesia; it was found from the initial implementation stage of the BPN GPS CORS, that the spatial and temporal variation in achievable accuracy of real-time coordinates is exist. The variations were sometimes exceeding the tolerable coordinate differences. For overcoming this problem, the coordinates of a rover station should be determined in multi reference station mode whenever needed, rather than in a closest single reference mode. The data processing system of BPN GPS CORS should handle these positioning modes in automatic and adaptive manner.

6. OPPORTUNITIES

Although in realizing the good and reliable BPN GPS CORS network there are several challenges and limitations that have to be properly taken into consideration, the opportunities are also enormous. The first opportunity come from the facts that still many land parcels have to be registered and vast areas to be mapped in large scales, e.g. 1:1000 and 1:2500, for making cadastral maps, as indicated by data shown in Tables 1 and 5.

Table 5. Status of cadastral mapping in Indonesia (2008 status).

Region	Non-forest area (ha)	Mapped (cadastral) area (ha)	% of mapped area
Sumatera	33.196.259	3.254.673	6,85
Java	10.923.034	2.852.905	21,50
Bali-NusaTenggara	5.195.391	651.324	9,08
Kalimantan	23.995.628	1.562.350	2,92
Sulawesi	10.429.888	1.084.665	5,82
Papua-Maluku	9.191.206	85.500	0,21
Indonesia	**92.931.407**	**9.491.417**	**10,21**

With about 55% land parcels still to be certificated (e.g. about 48 million parcels), and about 90% area still to be mapped (e.g. about 83 million ha), indeed the opportunity for BPN GPS CORS is enormous. The acceleration of this land registration and mapping process can be speed up by using BPN GPS CORS networks all over Indonesia.

Next opportunity comes from the new national program just launched by the Indonesian government, namely the Masterplan of Acceleration and Expansion of Indonesia Economic Development 2011-2025 program, which is termed as MP3EI program in Indonesian language [*CMEARI*, 2011]. The vision of this program is to create a self-sufficient, advanced, just, and prosperous Indonesia in 2025, through the following three main strategies, namely: (1) economic potential development through Economic Corridors, (2) strengthening the national connectivity, and (3) strengthening national human resources capability and science & technology.

The first MP3EI strategy that is related to development of economic corridors in Indonesia (see Figure 5) will require support from land administration process in the corresponding region. Development and investment in certain area will require certainty and assurance on the legal status of land in the area. Therefore, to initiate the development in certain economic corridor, then the land administration process should preferably be finalized beforehand. Based on data given in previous Tables 4 and 5, it can be realized that there are still a lot of efforts needed in order to finalize land registration and cadastral mapping in all six economic corridors shown in Figure 5, and in this case the BPN GPS CORS has a tremendous opportunity to contribute in speeding up this process.

In relation to second MP3EI strategy, namely strengthening national connectivity, the BPN GPS CORS can also contribute. This strategy consisted of 4 (four) national policy elements, namely National Logistic System, National Transportation System, Regional Development, and Information and Communication Technology (ICT) [*CMEARI*, 2011]. In tis regard, BPN GPS CORS will certainly can play a role in strentghening the National Transportation System and also Regional Development.

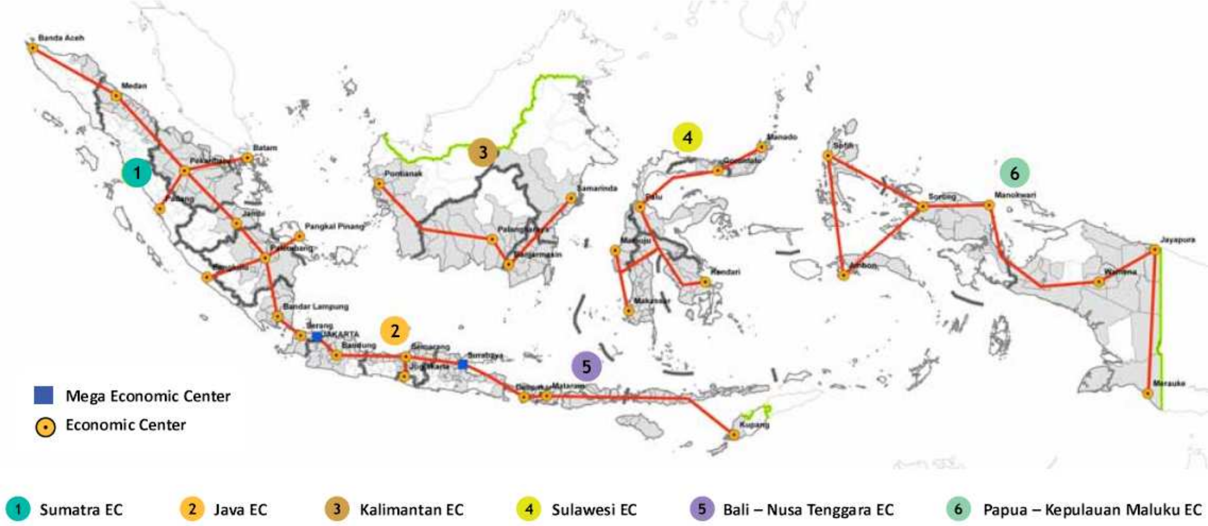

Figure 5. Six Economic Corridors (EC) of Indonesia, from *CMEARI* (2011).

GPS BPN CORS, with other existing GPS CORS in Indonesia, have also tremendous opportunity to contribute for natural hazard mitigation process. Due to its geological nature, Indonesian region is prone to earthquakes, tsunamis and volcanic eruptions [*Hamilton*, 1979]. In general, each year about 450 earthquakes with magnitude larger than 4.0 occur in Indonesian region. The earthquakes in sea may generate tsunamis on seashore. Indonesia has also 129 active volcanoes and 271 eruption points as a consequence of interactions and collisions among those plates The most populated island in Indonesia (i.e. Java) has also the most number of active volcanoes, and according to [*Katili & Siswowidjojo*, 1994] around 10% of Indonesia people live in the area endangered by the volcanic eruptions. Considering is rugged topography and usually heavy rainfall, landslide is also one of prominent geohazards that continuously affecting Indonesia.

Considering the aforementioned hazard-prone nature of Indonesian region, the systematic and sustainable (natural) hazard mitigation program is very important for Indonesia. In this case, the GPS CORS networks in Indonesia can have good contribution, especially in identifying and mapping the hazard prone areas and in providing the early warning on the coming of hazard events.

6. CLOSING REMARKS

Although in establishing, operating and maintaining the good and reliable BPN GPS CORS network there are several challenges and limitations that have to be properly taken into consideration; however its future and opportunities are also very promising.

In the future, by utilizing the GNSS receivers which can also observe other navigation satellites (i.e. Glonass, Galileo, and Compass) besides GPS satellites, then it can be expected that the performance of BPN GNSS CORS network will also significantly increase.

Finally, it should also be emphasized that if professionally managed, BPN GNSS CORS can generate a substantial amount of revenue for BPN and also cadastral private sector. Therefore, the business prospects and plan of the BPN GNSS CORS should also be prepared.

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BIOGRAPHICAL NOTES

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