Potential use of LADM in cadastral data management in India

Anandita SENGUPTA (India), Debanjan BANDYOPADHYAY (India), Christiaan LEMMEN (The Netherlands) and Anne VAN DER VEEN (The Netherlands)

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SUMMARY

A Land Administration System (LAS), with its cadastral component, is the infrastructure that facilitates the implementation of land policies to attain sustainable development.

The availability of a digital, up-to-date, complete and easy accessible cadastral database has become a primary requisite for undertaking an efficient land administration and/or developmental planning decisions for any country.

This paper highlights the possible advantages of having a digital cadastral database over the traditional paper-based cadastral systems, and how such digital cadastral maps with acceptable accuracy levels can be used for operationalising the concept of the Land Administrative Domain Model (ISO 19152) in an Indian perspective.

In this direction, we have demonstrated a method of preparing a seamless digital cadastral database using GIS and image interpretation techniques for a sufficiently large area of about 326 sq. km. Geo-Eye1 merged data was used for this purpose in combination with paper-based cadastral maps and limited on-site surveys. This approach can be considered as an (temporal) alternative to a complete cadastral re-survey. A cadastral resurvey is expected to be a time consuming and costly approach where there is an urgent need for cadastral data with reasonable quality urgently.

This paper presents the results of a first step of a broad approach to reconstruct colonial cadastral maps and related registers with land records for various purposes, amongst others, spatial planning one of the important aspects which is based on a reliable overview of people-land relationships.

The paper will then develop the LADM based options on:

1. How to convert and link the existing (colonial) maps and records to prepare a digital database based on the LADM standard?
2. How to document and publish the geometric quality of the existing maps?
3. How to make the existing maps and records up to date (in the digital LAS)?
4. How to integrate the more accurate data after the re-survey?

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1. INTRODUCTION

Cadastral maps and related land records must reflect the daily changes in the framework arising from the land development. This means the land administration is of a dynamic nature. The mapping of land parcels is a never ending job; as it must be constantly updated to keep pace with the subdivision, consolidation or mutation of land boundaries etc. Hence, updating is considered as one of the essential activities in a land administration. In this regard, many developed and developing countries have introduced Land Administration Systems.

India has still remained far away from such developments and is yet to reach a position of competence (Habibullah and Ahuja 2005). During late 1990s, a pilot project was carried out in the states of Andhra Pradesh, Bihar, Kerala, Orissa and West Bengal for digitization of paper-based cadastral maps. However, the project landed up with different problems because of varying size and quality of maps available, absence of standards on accuracy to be maintained in digitization, quality of equipment to be used and the amount of cost involved. Recently, an initiative called National Land Records Modernization Programme (NLRMP) is taken by the Department of Land Records under Ministry of Rural Development; Government of India for modernization of land records system across the country (NLRMP Guideline, 2008). However, so far application of such guideline over a large area, using VHR imagery has been limited. In addition, there are certain discrepancies in the sequence of method proposed for digitization.

This paper highlights in the possible advantages of having a digital cadastral database over the traditional paper-based cadastral systems, and how such digital cadastral maps with acceptable accuracy levels can be used for operationalising the concept of the Land Administrative Domain Model (ISO 19152) in an Indian perspective. In this direction, we have demonstrated a method of preparing a seamless digital cadastral database using GIS and image interpretation techniques for a sufficiently large area of about 326 sq km. Geo-Eye1 merged data was used for this purpose in combination with paper-based cadastral maps and limited on-site surveys. This approach can be considered as an (temporal) alternative to a complete cadastral re-survey. A cadastral resurvey is expected to be a time consuming and costly approach where there is an urgent need for cadastral data with reasonable quality urgently.

This paper presents the advantages of digital cadastral maps – with a focus to spatial planning in section 2. This focus is further detailed in a framework in section 3. The approach to reconstruct colonial cadastral maps and related registers with land records for various purposes is briefly introduced in section 4. The paper will then discuss the LADM based functionality in an approach of reconstructing colonial cadastral map for the purpose of spatial planning in section 5.

2. ADVANTAGES OF A DIGITAL CADASTRAL MAPS – WITH A FOCUS TO URBAN PLANNING AND LAND READJUSTMENT

The existing land administration system of India is a British legacy, based on the village as an administrative unit. Since independence except a few, as such efforts have been made in India to revise or update the colonial cadastral maps and registers. As a result, colonial cadastral maps[1] and land records available today are mostly outdated and do not always reflect the realities on the ground either in relation to ownership or plot boundaries.

The updating of those maps on paper and related registers as anticipated being very cumbersome for several reasons:

- In the conventional setup in India, cadastral maps and land records are maintained separately in different organizations. In this case, updating of plot boundaries changed by mutation and modification of other title information takes a long process,
- The cadastral maps used to prepare on a low quality paper or cloth, are subject to various kinds of degrading factors. Hence in most cases maps are in poor shape and torn due to lack of upkeep, and:
- The maintenance of an infrastructure to continue with the earlier practice also involves an extremely high cost. All these above mentioned factors together reinforce the need for digital (seamless) cadastral map with updated information for India (Habibullah and Ahuja 2005).

Modernization of the system is relevant in this context. Modern digital systems allow for upgrading of data quality (complete data, reliable and with a proper linkage between spatial and administrative data. The upgrading of accuracy can follow.

A Land Administration System (LAS) covers land registration (land records) and cadastre (cadastral map). The combined process is called land administration and LAS is the environment in which this process takes place. A LAS can be paper based or digital or a combination of both. Processes include adjudication (the juridical/administrative and technical procedures to document property, use and other land rights, which may be informal or customary), establishment of and transactions on land rights and information provision.

Information provision can support in multiple purposes:

- taxation,
- legal or tenure security,
- support of land market and mortgage industry,
- support in spatial planning

Different organisations can be involved in the maintenance of a LAS, public and private. Implementation can be centralized or decentralized. See also Bogaerts and Zevenbergen

[1] A cadastral map contains systematically arranged information on all properties (i.e. parcels) within a given village or district. The boundaries of properties are normally shown on large scale maps, for example 1:4000 to 1:8000 as for the 'colonial cadastral maps' in India. Conventionally, cadastral maps together with village registers (land records), in which further details of the property, namely ownership, land use, its value and size etc. are used for revenue collection and also to ensure the security of the property to its owner.

(2001), UNECE (1996). In some cases a LAS is built up systematically (all properties in one area), sometimes sporadically (properties are included after a transactions.

The support of a LAS in urban planning and development includes:
- land re-adjustment and land reform;
- planning and development of infrastructure;
- utilities; and
- rural development, e.g. land consolidation or re-allotment) and other.

Combinations of approaches are possible: for example the planning of new infrastructure combined with rural land consolidation – to avoid negative impact because a group of parcels in use by a farm is 'sub-dived' in two groups (evident with subdivided original parcels). Land re-adjustment is a popular approach in urban planning.

A classical definition of land readjustment is "Process whereby land owners pool their lands and then resubdivide[2] the assembled property, setting aside a portion of the total parcel for improved access and infrastructure and an additional portion for sale or commercial development to pay for the improvements to the property" (Doebele, 1982). A more modern definition is: "Land readjustment gives all affected property owners in a redevelopment district the power, by majority vote, to approve or disapprove the transfer of land rights to a self-governing body for redevelopment; instead of buying out all existing property owners using eminent domain, the agency invites property owners to become stakeholders and to contribute their real assets to the project as investment capital; in return, the agency promises to give each owner a land site of at least equal value in the vicinity of the original site upon completion of the redevelopment; after all properties in the district are assembled, the combined land sites are subdivided according to a master plan designed and approved by the stakeholders" (Li & Li, 2007).

In both definitions the owners, living in an "project[3]" area, play a key role in the development. They contribute with their lands into the plan. There will be a systematic reductions applied to their land rights (in area or in value) and their land rights can be re-allocated (transferred). This is a fundamental different approach the expropriation or forced eviction (without any compensation – resulting in social problems). The value of the land will increase as an impact of the development. This increase in value is captured to finance the implementation of the plan.

Van der Molen made an overview of benefits and disadvantages of land readjustment for citizens and governments (Van der Molen, 2012). Benefits of Land Readjustment for participants are in the citizen participation (win-win situation for citizens who can stay in the area and the government getting lands available); in the realization of public infrastructure not at the expense of a single individual (by expropriation) but on the community (by re-adjustment with systematic reduction); in assumed increase of value despite the reduction % of size; in sharing financial costs and benefits between local community members and with

[2] 'Resubdivide' in the sense of 'redistribute'.
[3] The boundaries of the area where land readjustment is applied are carefully determined and fixed

local government. There is a conversion into plots with better service, access and infrastructure and other physical improvements (sewerage…). Ownership rights are safe guarded because of recording. This is one of the specific requirements in LADM applications: an overview of the exiting situation is ‘linked’ with the new situation: every owner will get his/her (reduced in area but increased in value) property rights back. Disadvantages to citizens are in: owners are forced to participate if they are against (but voluntary approaches are possible). There is a risk: will value increase happen? The distribution of serviced plots is to original owners, thus not necessarily the poor (LR does not solve may be even encourage gentrification). One more disadvantage is in the fact that the reduction % (the lands to be used for planned infrastructure, schools, parks etc.) can be too high; owners are left with too small plots. Free riders behaviour of abutting neighbourhoods causes tensions. And: what about secondary right holders: renter’s lessees. Those are the real users. Do they participate – or only the owners?

Benefits for the governments are in the fact that there is no need for initial investment as in case of eminent domain; eminent domain is costly and takes long time because of red tape and citizen-resistance. There is no need to upset citizens; they are usually upset by sold-out option. There is no need to burden the tax payer: at the contrary costs of eminent domain have to be met by public. There are no problems with providing evidence of public interest when calling for eminent domain. As said: land acquisition is shared, there is no need to expropriate the individual: property owners together contribute % of their lands to ‘general purpose’ in a ‘systematic reduction. Finally it can be mentioned that reserved land can be sold for cost recovery of the project. Some disadvantages can be recognized at government side: the Land Readjustment procedure is not always quicker than eminent domain, because convincing citizens might take time. It is necessary to know who owns what: a complete and reliable overview of the land rights is needed. A further disadvantage may be that (some) owners who want to maximize their .benefit. There is a need for skilled personnel for negotiations and valuations. In some cases even with a high reduction % sometimes not enough good quality urban space might be created. It should be observed that a reduction % not always possible, need for land stocker other options to create space. Speculation occurs: (serviced) plots remain idle and are sold several times. This could be a reason to stop the land market during development and implementation. Van der Molen concludes that land readjustment is not the perfect tool for every condition in renewal of built-up areas (see also Turk & Korthals Altes, 2011) and also that land readjustment is only one of the several possibilities: it can seldom be designed in a vacuum with unique regulatory structure. In any case the approach has been applied in many countries with a lot of success and since many decades. A proper land administration is basis. A proper land administration is always a requirement in case of selling existing rights to land parcels or in case of expropriation in the benefit to the development of a spatial plan.

3. A FRAMEWORK FOR UPGRADING QUALITY OF LAND ADMINISTRATION FOR URBAN PLANNING

In India there is a lack of reliable land information (land rights, land use rights) as a basis for spatial planning.

Resurvey is considered, but this solution will be time consuming because the existing records have a legal meaning. This link with the past cannot be simply disturbed by a cadastral resurvey.

An alternative approach is to respect the contents of the existing maps and records combined with a quality upgrade: make the existing records and maps up to date as basis for a spatial planning. Why does this alternative approach not conflict legal meaning?

We placed this situation in a framework for quality upgrading of land administration for urban planning, see Figure 1.

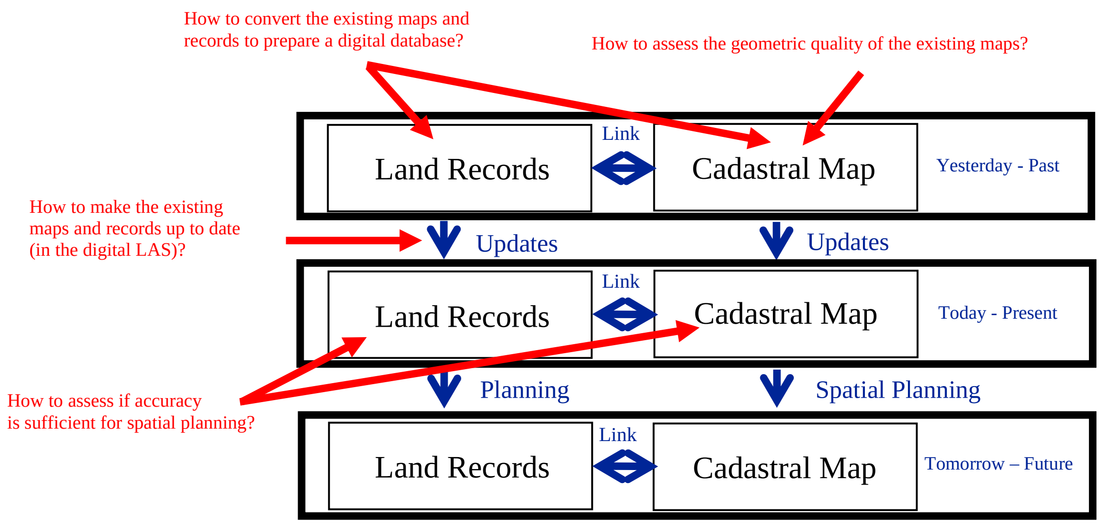

Figure 1: framework for quality upgrading of land administration for urban planning

Land administration in India has been set up under British institutions; this can be considered as ‘yesterday’ (past). The situation in the land administration as it is ‘today’ (present) does not reflect the actual situation in the field because the system is not well maintained, neither all updates (as a consequence of land transactions) are included nor the updates have been done in a synchronized way on the map in relation to the records. For this reason the LAS is not yet ready to support spatial planning as a basis for the development of the situation ‘tomorrow’ (future). Up to datedness is needed either to identify the owners of lands where infrastructure has to be developed or lands to be used for other public purposes in the future or for urban development where the lands have to be available to the government or project developer or other organizations before the development takes place. Another purpose is land consolidation and land readjustment allowing exchange of lands in case properties are divided because of new infrastructure. Land consolidation also allows the concentration of land rights at one side of the new infrastructure line. Land consolidation is traditionally focusing on rural areas’ and land readjustment to urban areas’. The approaches are similar and require good land administration. Land can also be bought or may be expropriated (with an acceptable compensation); this requires actual information on the legal situation. The 3rd dimension of property rights may be relevant in some cases; e.g. when it is about subsurface infrastructure, including utilities.

All this concerns both the ‘administrative part’ of a land administration (the legal/administrative attributes on property rights, value and land use) and the ‘spatial part’, this is the related spatial representation of parcels on a cadastral map. Spatial and administrative parts need to be linked in a proper way over time; also after updating. If historical data are kept into the system it is possible to look back in time where the administration of properties is concerned.

Different methods can be used to update the quality of attributes and spatial data. Public inspections or field checks with participation of the community may be used to find the existing owners after inheritance, marriage, transactions, prescription, expropriations, recognised claims by courts or other ways of acquiring lands. The accuracy of the maps can be improved by renovation methods, see Salzmann (1996) and Salzmann et al (1997), Song (2008) and Kumar (2006). Lemmen and Zevenbergen (2010) provide references experiences and references on the use of satellite images for first cadastral data acquisition. Resurvey is another method, but this is expensive and time consuming. In this paper we will present ‘an improved concept of map representation’, or ‘an innovative concept of map improvement’ based on satellite images.

4. CONVERSION OF EXISTING LAND ADMINISTRATION

The conversion work was carried in the state of West Bengal, located in the eastern part of India, see Figure 2.

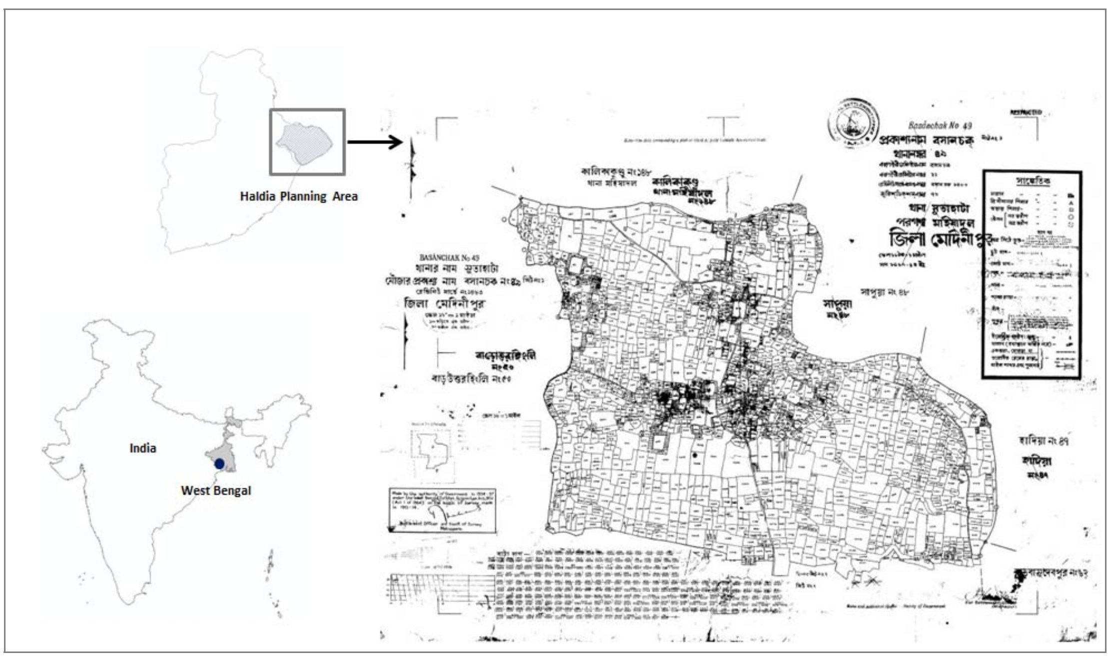

Figure 2: Location of Haldia, West Bengal with an example of colonial cadastral map available

The state has a rich legacy for cadastral mapping which initiated from 1888 and then steered through different phases. Because of the high population density, about 420 persons per sq. km, the average land holdings size within the state is among the lowest in world, about 1 acre[4] per person. In addition, the state has witnessed land reforms activity for several times during the post-independence era, resulting into rapid fragmentation of the land parcels. Hence, the cadastral-level parcel mapping of this state is a challenging task.

In West Bengal, the unit of survey for cadastral mapping and land records is a mouza, i.e. a revenue village. Following the survey principle of 'from whole to part', the boundary of the mouza under survey was first subjected to theodolite traverse and then ground details were surveyed and plotted by plane table or chain survey. A uniform method of survey and scale of mapping was followed for the entire state.

For the present study Haldia, located at the southern tip of the state West Bengal, was selected as the study area, see Figure 2. In particular, the area is located in the estuarine reaches off the River Bhagirathi and at the confluence of two major rivers. The planning area of Haldia covers an area of 326 square km including 258 revenue villages (i.e. rural area), and 26 municipal wards (i.e. urban area). The entire planning area is covered by 310 colonial cadastral maps at a scale of 1:3960 graphically representing individual plots (locally known as 'dag') with the respective plot no. During the last few decades, the area is emerging as one of the major industrial hubs of India, and as a consequence it has experienced a drastic change in land-use pattern. Moreover, being located at lower deltaic region, the area is also prone to river dynamics, which resultantly change the plot boundary (locally known as 'aals').

The proposed method to prepare digital cadastral map using Very High Resolution (VHR) satellite imagery and limited GPS survey was designed by adapting the technical manual of the NLRMP mission. For this purpose, Geo-Eye1 (merged) images having 0.45 meters spatial resolution with 4 spectral bands and 310 colonial cadastral maps of the area were used. Besides, other maps including topographic maps, planning area map provided by the Development Authority were used for ground verification.

Paper-based (island) cadastral maps collected from the District Land & Land Reforms (DLRS) office were scanned in 8-bit scale with 300 Dots Per Inch (DPI) resolutions and saved in Tagged Image File Format (TIFF) format. Depending on the availability, a few scanned maps were also readily obtained from the DLRS office. The scanned cadastral maps were then geo-referenced with respect to the Geo-Eye1 (merged) imagery. An affine (i.e. polynomial 1st order) transformation was used to geo-reference the scanned maps as the area is mostly flat with some undulation in a few parts. For each map, 10 to 15 identical points both on the merged image and on the scanned cadastral maps were used as 'control points' to define the coordinate location. In addition, a few 'control points' were also taken along the boundary by matching the edge of the individual mouza to set the adjacent mouza accurately, see Figure 3.

After geo-referencing, the boundaries of the cadastral maps were digitized in a polygon layer. Individual parcels of each cadastral map were then digitized as a separate polygon layer.

[4] 1 acre = 0.404 685 642 24 hectare

Subsequently, all the individual parcel layers were merged to make a seamless parcel layer covering the entire area. ‘Gaps and overlaps’ between the original maps were moved out by taking the average location between all identical points which are represented on 2, in exceptional cases 3 or 4, neighbour maps. Then topology was built for the layer to check any gaps in between the parcels or the parcels overlaying on each other. Later this digitized parcel layer was overlaid on the Geo-Eye1 (merged) imagery to update the land use of each parcel through visual interpretation.

Figure 3: Control point selection by edge matching

Using the methodology mentioned in the here above, a digital, seamless, cadastral database with links to the land records was prepared for an area of 326 sq. km based on the available colonial cadastral maps of the area and Geo-Eye1 imagery. Figure 4 is showing the different steps of such map preparation.

Accuracy, defined by Enemark (2012) as ‘fit for purpose’, of any spatial database is the prime requirement from a user perspective (Ghosh 2009). Likewise, accuracy of the digital cadastral-level parcel map prepared was also evaluated – but the details are not so relevant in this paper. Most important is that the results of the assessment can be included in the LAS. This is also a condition in use of LADM. A similar condition is in area attributes. There is area difference between the official record and the digitized map. This has to be documented. Further more there are gaps and overlaps which have to be eliminated. This means that individual boundaries are changes (not polygons, but boundaries). It should be possible to document this again – it has also impact on areas.

To our best knowledge, this attempt to prepare a digital (seamless) cadastral map with acceptable level of accuracy, for a large area using GIS is first in its kind in India. With the advent of GIS techniques, this map can be overlaid on the high-resolution satellite imagery to update the details of the area within short time. Moreover it will help in monitoring the changes in land use across parcels (after acquisition), breaking down or consolidation of parcels, areas which has gone either into river or has been added; thereby needing change in the DLRS records.

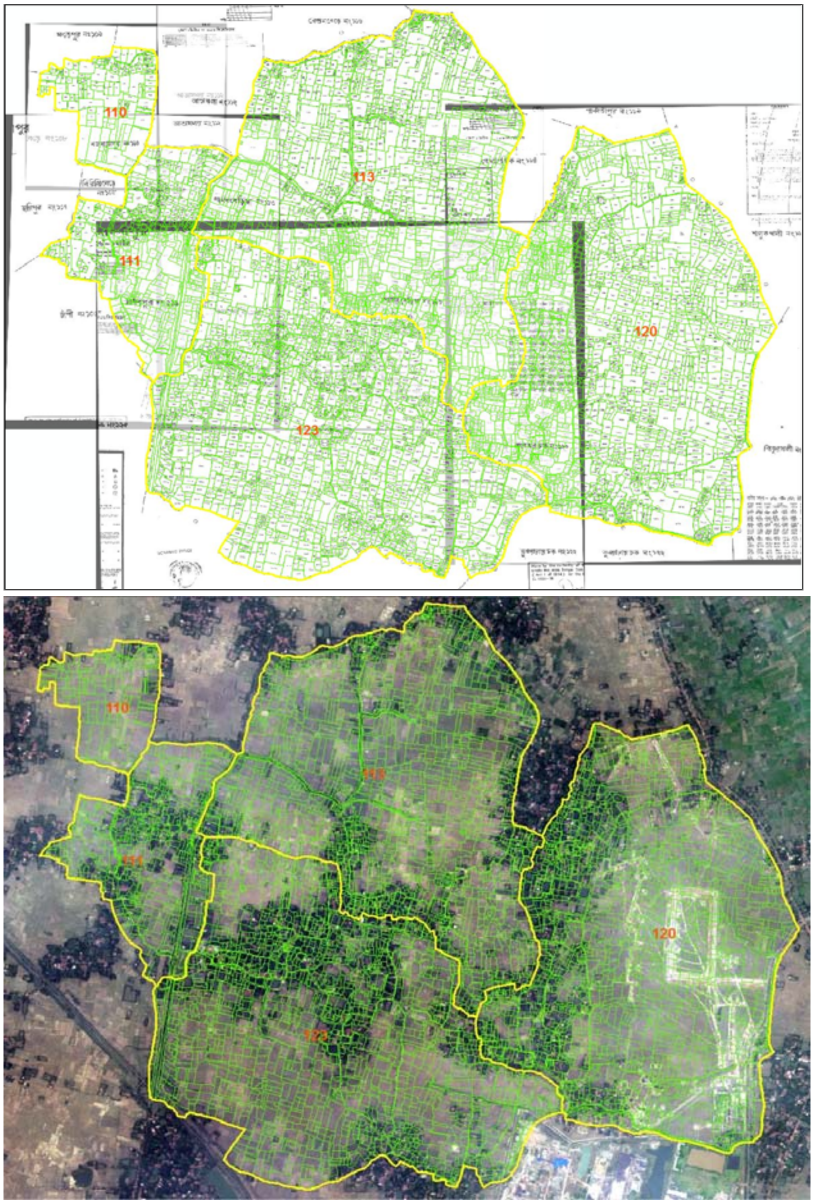

Figure 4: Preparation of parcel layer from geo-rectified cadastral map (above); Overlaying of digitized parcel layer on the VHR satellite image (below)

The methodology can be adopted to prepare a seamless and updated cadastral map for a sufficiently large area with limited field survey where require. The methodology is formulated in accordance with the national mapping standard, so that it can be used with any other spatial datasets at any scale. However so far, no standardized framework for projection, scale, contents, accuracy in surveying and mapping is available in India; which led to a serious barrier to the creation of national geo-spatial data infrastructure (Kumar 2008).

Moreover, digital cadastral maps with updated land related information is one of the prime requisite for any Land Information System (LIS) as a component of a Land Administration System. Consequently, this can be used as a basis for a cadastre-based LIS preparation. LADM is relevant here.

5. LADM FUNCTIONALITY FOR THIS APPROACH

According to the developed frame work we have the links between the land records and the cadastral maps in the past (“yesterday”), the actual situation (“today”) and the future situation (“tomorrow”).

This section starts with a discussion on conceptual level on how to convert and link the existing (colonial) maps and records to prepare a digital database based on the LADM standard? And: how to make the existing maps and records up to date (in the digital LAS)? This discussion includes LADM existing functionality. Here it can be observed now that:

LADM has the functionality to link cadastral maps and land records based on BAUnit identifiers and/or LA_SpatialUnit identifiers. LADM has the “history” functionality to include all updates (this means all documented land transactions in LA_Source) in the land records to create the situation as it is today. The same is valid for documented updates in the cadastral maps. It should be remembered here that in our case from India the land records have been updated based on documented transactions (source documents), but the maps are still the original maps – without updates. Two approaches are possible now:

– a “transaction by transaction approach” where the cadastral map is updated in case the historical transaction concerns a subdivided or merged spatial unit. The new boundary can be “roughly” introduced (using imagery if possible) to the map. Imagery may be supportive. The problem is that topographic and land use boundaries are not always cadastral boundaries. A specific quality label has to be related to this boundary. This is possible, LA_BoundaryFaceString inherits quality (DQ_Element) from class VersionedObject.
– “direct updating of the historical situation” to the existing situation by a combination of re-use of boundary information from the colonial maps combined with imagery as basis for identification of new boundaries. The problem is again that topographic and land use boundaries are not always cadastral boundaries. Field inspections and participatory approaches are needed to get the complete actual link between today’s up to date records and the map. Again the labelling is important.

In both case checks are possible within a LADM constellation. In principle all rights and related right holders should have an appearance in a spatial unit. It should be further observed that LADM is a model for land administration. It is not a model for *design* of a spatial (urban) plan. LADM can be *in support* to design processes in spatial planning or, more specific, to land consolidation/readjustment processes. The LADM does not include core data for planning. But it included core data in support to the design and the implementation of spatial plans. Such *support* to land consolidation/readjustment processes includes information management on people land relationships (today and tomorrow):

- documentation of transactions and data updating as results of transactions: buying, selling, exchanging of rights. This is of course relevant if the land market goes on when spatial plans are implemented; for example to purchase land for a municipality or other authority and also expropriation,
- area management is needed. There will be different areas for the same spatial unit. This is possible in LADM. One spatial unit can have many areas.
- calculations of systematic reduction. It may be required (in land consolidation or land readjustment) to apply a systematic reduction on the area or value of the land. Note: valuation data are modelled in LADM in an external class, see Annex K of (ISO, 2012), and:
- checks on completeness (in land consolidation/readjustment). The existing situation “today” (with its history arriving from “yesterday”) can be in one level. The newly designed situation (map and records) can be in another level. The required relationship functionality can now be used here. In LADM this concerns an explicit association between either spatial units, or between basic administrative units. The check on completeness can be applied by checking spatial units in the new situation without required relationships to the existing situation. If a required relationship is missing the situation has to be checked. Rules can be built for this. The same is valid the other way around. If a required relationship is missing from the existing situation to the new situation checks have to be performed. Rules can be built for this.

Re-allocation algorithms are not included in LADM. Re-allocation algorithms may generate a spatial plan based on a set of rules combined with the area or value of contributed land rights (with a systematic reduction applied).

Other questions on functionality in LADM are: how to document and publish the geometric quality of the existing maps? And: How to integrate the more accurate data after the re-survey? The answer is in the functionality provided in Surveying and Presentation Package of LADM, as analysed in Van Oosterom et al (2011):

- data acquisition can be based on variety of approaches (low cost / high tech), which not always involves conventional terrestrial surveying. Observations may require transformations and adjustments, or other corrections, before the cadastral geodata for spatial units can be edited. Those transformations and adjustments can be documented again. All different types of the geodata acquisition can be represented in LADM. However, procedures for data acquisition itself are not included in the standard. Quality aspects of data can be represented based on DQ_Element types from ISO 19115,
- class LA_Point includes the attributes pointIdentifier; estimatedAccuracy; interpolationRole (this is the role of point in the structure of a straight line or a curve, e.g. end, isolated, mid, mid_arc, or start); monumentation (this is the type of monumentation in the field, e.g. beacon, cornerstone, marker, not_marked); originalLocation (this is of type GM_Point and concerns the calculated coordinates from original observations in a Coordinate Reference System CRS); pointType (e.g. geodetic control points, or points with or without source documents); productionMethod; transAndResult (transformation and transformed location, the transformed location is a new version of the point).

Transformations include for example affine transformations but also mathematical computations such as least square adjustments. Note that there may be 0 or more transAndResult attribute values, implying that there is one (in orginalLocation) or more (in transAndResult) GM_point value for every instance of a LA_Point object class,
- LA_SpatialSource (as a specialization from LA_Source) contains as attributes measurements, procedure and LA_SpatialSourceType. LA_SpatialSource is a document providing facts, for example fieldsketch, GNSS survey, orthophoto, relative measurement, topographic map, or even video. The document can be used as authentication for the agreement between neighbors – and also for reconstruction of boundary points in case of disputes. It may be a combination of paper (to be scanned later in the offices) and digital files with observations, and:
- LA_BoundaryFaceString – a boundary is a set of points that represents the limit of an entity. A boundary face string is a boundary forming part of the outside of a spatial unit. Boundary face strings are used to represent the boundaries of spatial units via line strings in 2D. This 2D representation implies in a 2D Land Administration system a 2D boundary, or in a 3D Land Administration system a series of vertical boundary faces. In that case an unbounded volume is assumed, surrounded by boundary faces, which intersect the earth's surface (such as traditionally depicted on the cadastral map). Attributes are: boundaryFacestringId; the geometry (on the ground) represented via a GM_MultiCurve; locationByText (a description of the boundary in words).

Least squares adjustments or any other adjustment approach may be used to compute an optimal solution. This means all observations get corrections in such a way that the adjusted observations will fit into the mathematical model. E.g.: in 2D plane geometry the sum of the angles in a triangle will be equal to 180 deg. This mathematical condition is generally not valid for the original observations due to (small) observation errors. The magnitude of the corrections to be applied to the observations can be used for testing to identify outliers. The least squares adjustment methodology is a good tool to get an optimal solution in networks where redundancy exists. The results of the adjustment process are calculated coordinates which can be represented in LA_Point under the attribute originalLocation.

6. CONCLUSION AND RECOMMENDATION

A frame work for upgrading and re-use (for urban planning) of colonial cadastral maps has been presented. The LADM provides sufficient functionalities to support the requirements where the data management is concerned. But LADM is neither a survey system nor an application for performing complex adjustments of newly surveyed data to the map. Further, LADM is not a design system for urban (or rural) planning.

It is recommended to develop a specific domain model for land consolidation and land readjustment based on the LADM. See also (Lemmen et al, 2012). Such a model should the data for representation of the existing situation (*de facto* land use "today"), the valuation data, the input alternatives for re-allocation algorithms (based on models or preferences) and the final result of land consolidation and land readjustment (the planned situation for "Tomorrow") for implementation in the field and inclusion of the new situation in the Cadastre and Land Registry.

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BIOGRAPHICAL NOTES

Anandita Sengupta Anandita Sengupta is a PhD student of the University of Twente, the Netherlands. Her research is focusing on the challenges that lie in the way of introducing a risk guided land use planning framework in the India in order to minimize the potential consequences from chemical accidents. She is also working as a researcher in the Institute for the Protection and Security of the Citizen (IPSC) of the Joint Research Centre, European Commission in Italy. She holds a MSc in in Geography and a MSc in Geo-information Science from the International Institute of Geo-information Science and Earth Observation (ITC) jointly with Indian Institute of Remote Sensing (IIRS).

Debanjan Bandyopadhyay is presently pursuing his research on risk information and decision support systems as a part of a PhD program at the University of Twente, the Netherlands. He also has a MBA degree in Information Systems and a Post Graduate Diploma in Environment Management from the University of Calcutta. Professionally, Debanjan presently heads the Environmental and Social Risk Management vertical for SENES Consultants (India) and has 16 years of experience on implementing diverse projects in areas like environmental information systems, impact assessment, risk analysis, audits, environmental policy and planning at the regional and national levels in India.

Christiaan Lemmen holds an MSc in Geodesy from Delft University of Technology, the Netherlands. He received a PhD from the same University for his thesis ‘A Domain Model for Land Administration’. He is sr geodetic advisor at Kadaster International and visiting Assistant Professor at Twente University (Faculty ITC), the Netherlands. He is chair of the

Working Group 7.1 'Pro Poor Land Management' of FIG Commission 7, and contributing editor of GIM International. He is director of the FIG International Office of Cadastre and Land Records, OICRF. He is one of the co-editors of ISO 19152 (together with Uitermark and Van Oosterom).

Anne Van Der Veen is professor of Spatial Economics (Faculty of Engineering Technology) and professor in Governance and Spatial Integrated Assessment (Faculty ITC) at the University of Twente, the Netherlands. His expertise is in Regional Economics, Integrated Water Management, and Risk Management.

CONTACTS

Anandita Sengupta
University of Twente, Faculty of Geo-Information Science and Earth Observation
PO Box 217
7500 AE Enschede
THE NETHERLANDS
E-mail: a.sengupta@utwente.nl; anandita.sengupta@jrc.ec.europa.eu
Website: www.itc.nl

Debanjan Bandyopadhyay
University of Twente, Faculty of Geo-Information Science and Earth Observation
PO Box 217
7500 AE Enschede
THE NETHERLANDS
E-mail: d.bandyopadhyay@utwente.nl
Website: www.itc.nl

Dr. Ir. Christiaan Lemmen
Cadastre Land Registry and Mapping Acengy
P.O. Box 9046
7300 GH Apeldoorn
THE NETHERLANDS
Phone: +31 88 183 3110
E-mail: chrit.lemmen@kadaster.nl
Website: www.kadaster.nl

Prof. Anne Van Der Veen
University of Twente, Faculty of Geo-Information Science and Earth Observation
PO Box 217
7500 AE Enschede
THE NETHERLANDS
Phone: + 31 53 4874484
E-mail: a.vanderveen@utwente.nl
Website: www.itc.nl