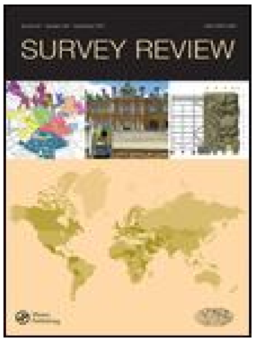

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Integrated geospatial evaluation of manual cadastral mapping: a case study of Pakistan

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Integrated geospatial evaluation of manual cadastral mapping: a case study of Pakistan

M. S. Ahsan*[1], E. Hussain[1] and Z. Ali[2]

Cadastral mapping in Pakistan is often sketched on paper or cloth and generally falls below cartographic standards, lacking details on coordinate systems, datum and directional information of parcel lines. Survey numbers for parcel identification also lack digital interoperability. Parcel measurements and ownership information are manually recorded in multiple separate registers. The objective of this study is to leverage geospatial technology for automation, auditing and validation of present manual cadastral mapping in Pakistan. Only 62% of the parcel geometry could be automated due to irregular parcel shapes. However, the process revealed some interesting discrepancies in cadastral datasets. Geospatially calculated areas and rectangular base areas are approximately eight acres less than the officially notified estate areas recorded in the field book. This study advocates using geospatial technology to update manual cadastral mapping practices to help avoid such errors when validating existing datasets.

Keywords: Word, Cadastral mapping, Latha, Musavi, Parcel boundaries, Participatory GIS

Introduction

Land is an important natural resource for fulfilling basic needs and insuring humankind's continued survival on earth. The dynamic growth of population (UN, 2014) and its interaction with land has made it essential for the world to build capacity for proper land management. The Statement of Cadastre (1995), Bogar Declaration (1996), Cadastre-2014 (1998) and Bathurst Declaration (1999) are few examples of efforts made by the International Federation of Surveyors (FIG) in this regard, all of which propose that future development can be achieved by progress in land administration systems (Steudler *et al.*, 2004). Cadastre-2014, presented in 1998 as the future vision of land administration, proposes six statements. The statements two and four advocate the use of Information and Communication Technology (ICT) for land administration while abolishing the use of paper- and pencil-based cadastral systems (Steudle and Kaufmann, 1998). Most developed European countries computerised their land records in the 1990s and have since made these available in digital form (Dale and McLaughlin, 1999; Borzacchiello and Craglia, 2013). Austria initiated a project to computerise land registry data in the year 1980 and since 1991, also made integrated cadastral maps and land register data available online (Lisec and Navratil, 2014). Similarly, Malaysia adopted the computerised land registration system in 1990 and implemented e-Cadastre project in 2003 to make all cadastral maps available in digital format (Nordin, 2010). Several studies from around the world suggest the use of geospatial technology for upgrading manual cadastra l mapping into digital cadastral mapping (Demir *et al.* 2008 Srinivas *et al.*, 2012; Harvey, 2013).

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Cadastral system in Pakistan

Pakistan has a manual cadastral system which is deemed both inefficient and obsolete (World-Bank, 2006; Ali *et al.*, 2010). The system is decentralised and each province has its own Board of Revenue (BOR) to manually prepare, archive and manage their land records at three administrative levels i.e. province (level-I), district (level-II) and tehsil (level-III). In Pakistan, more than 90% of revenue officials and land owners believe that the current cadastral system can be made more efficient by using ICT (Ali, 2013). As expected from the 6th most populous country in the world (PRB, 2014), 190 million land parcels in Pakistan are owned by as many as 50 million people. The sheer volume of records has presented a challenge in shifting from manual to accurate digital cadastral records (Adeel, 2010; Mirza and Adeel, 2012). Moreover, existing land parcel records are disorganised. Information such as ownership, land rights, land type and land measurement for a single land parcel is often scattered across multiple manual entry registers and is therefore difficult to retrieve. The following paragraph provides brief information about cadastral system organisation and mapping in Pakistan.

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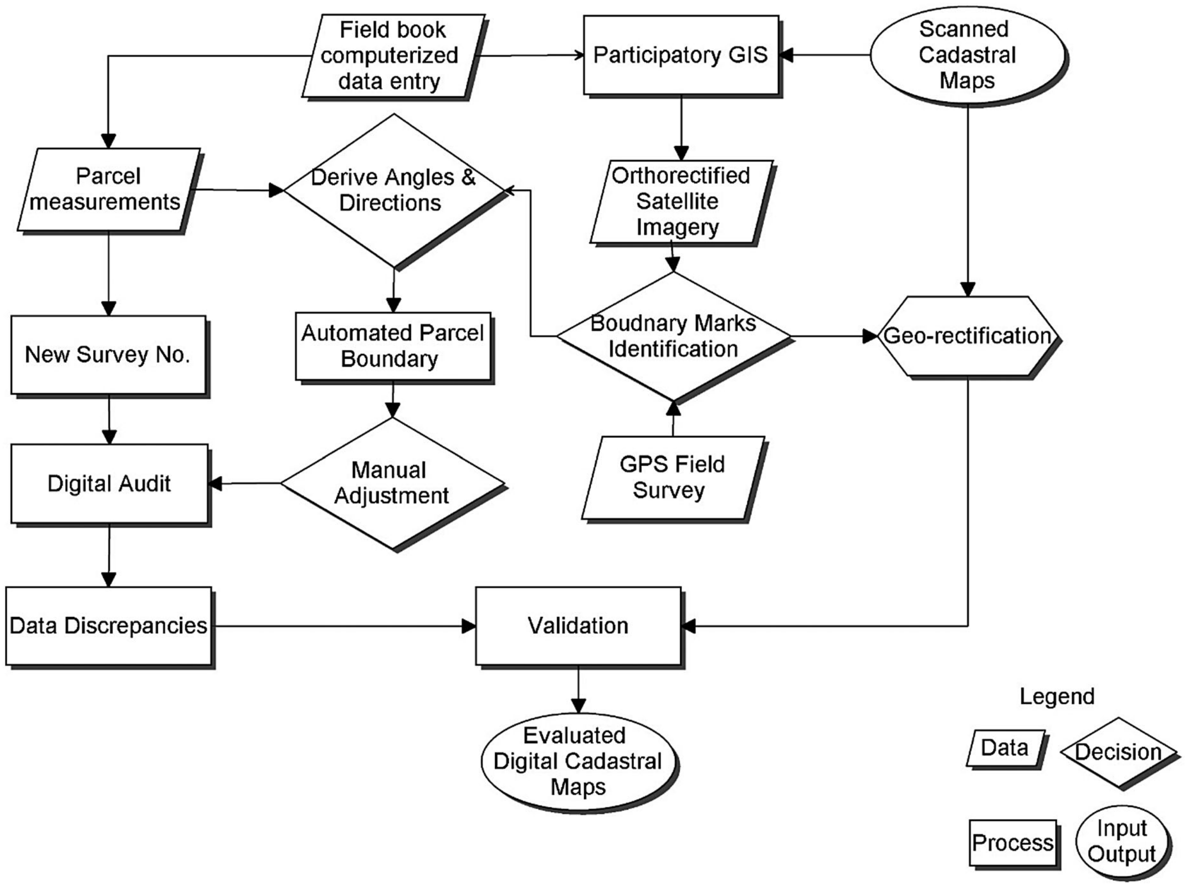
Table 1 Local measurement units and their equivalency

1 Karam	1.6764 m
36 × 40 Karam	1 Acre
1 Acre	4046.85642 m^2
10 Acres	1 Rectangle
25 Acres	1 Square

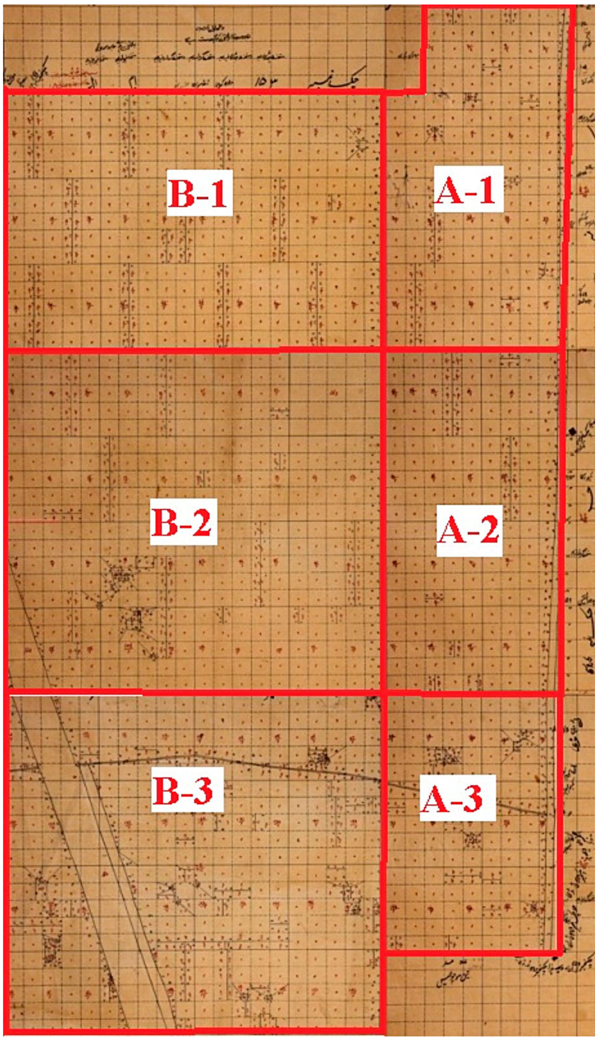
Cadastral mapping in Pakistan consists of a field book and cadastral maps. Field books contain attributes data prepared on the basis of physical field surveys. These attributes include parcel survey numbers, parcel dimensions, land type and total area of the parcel. The attributes information is prepared in graphical form on a paper called 'Musavi' or on a piece of cloth called 'Latha'. Field book and cadastral maps are prepared during land settlement which is supposed to be held once every 30–35 years, but is rarely ever arranged in actual practice (Raza *et al.*, 2005; Ali and Abdul, 2010).

Currently, Kishtwar and rectangular survey are the two main systems for cadastral mapping practised in the country. Land parcels in the Kishtwar survey system are arranged into irregular-shaped polygons, while Rectangular survey arranges them in regular polygons (rectangle and/ or square). A block in rectangular survey system consists of either 10, called *Mustateel* (rectangle), or 25 parcels, called *Muraba* (square) (Haq, 1995). In a rectangular survey system, some blocks and parcels may not be of regular form due to natural features and land mutation. More than 90% of the canal irrigated plane areas are based on the rectangular survey system. In this system, the actual boundary (legal) of a parcel may differ from the physical field boundary due to on-ground land use patterns. An actual land parcel may be subdivided into more than one field for various crop cultivation or irrigation conveniences. Karam is an official land measurement unit. Other related units and their equivalence in metric system are shown in the Table 1 (Tariq, 2011).

Existing cadastral maps contain no information about datum, selected coordinate system or related topographic details and do not comply with modern cartographic standards. The parcel survey numbers within a district are unique, but similar numbers are repeated for parcels in another district. Generally, in rectangular survey system, parcels are numbered according to block numbers. For example, parcel survey numbers of block number 1 and 2 are numbered as 1/1, 1/2, 1/3 … … . .1/10 and 2/1, 2/2, 2/3 … … .2/10. Similarly, parcel survey numbers of another district also follow the same survey number patterns. There are three types of boundary marks; tri junction pillars are used for identification of estate boundaries, mud or stones pillars for the identification of parcel boundaries and burji (pillar), to indicate any angular change in parcel lines. These boundary marks are physically erected/constructed on the ground during the land settlement process. They serve as a foundation for further legal demarcation and resolution of land encroachment disputes. However, there always remains a chance that these boundary marks may be moved from their original location, either intentionally or by natural events such as floods etc. The accuracy of converting a cadastral map



1 Methodology flow diagram



2 Study area cadastral map formed by mosaicing six (6) individual cadastral maps

into digital form depends highly on the precise placement of these boundary marks. Numerical information about angles and parcel line directions is not recorded on either the cadastral map or the field book (Adeel, 2010).

In order to address the above-mentioned problems, in 2006 the Punjab government introduced a land records digitisation initiative, in collaboration with the World Bank. This initiative, called Land Record Management Information System (LRMIS), commenced with an objective to convert attribute records into digital format. There was also a plan in place to investigate the best method to convert manual cadastral maps into Geographic Information System (GIS)-based formats (World-Bank, 2006). However, up till the year 2015, maps of only 3 out of 36 districts have been digitised (Govt. of Punjab, 2015). The manual digitisation of paper-based maps has thus covered merely 3.4% of the province. The project is progressing at an extremely slow pace and ignores the importance of on-ground verification of boundary marks. Indeed, geo-referencing and digitisation of old cadastral maps without incorporating proper parcel measurements and precise field surveys have resulted in a range of serious digitisation, mosaicing and topological errors in the system (Annexure A & B). The same accuracy issues were observed in the digitisation of paper-based cadastral maps into Digital Cadastral Database in Australia in the 1980s. Similar problems were also observed in Turkey (Demir and Çoruhlu, 2008; Bennett *et al.*, 2011).

Other related studies in Pakistan faced limitations similar to those encountered in the LRMIS project. The integrated geospatial approach adopted by (Ali *et al.*, 2012) can be considered both cost effective as well as time efficient. This method can further be improved by automating, auditing or validating the land parcel results and comparing them with official revenue records. Another study conducted by (Khan *et al.*, 2011) regarding parcel mapping in a selected district of Pakistan was compiled without incorporating field surveys of boundary marks and did not verify the digitised geo-referenced, cadastral maps-based parcel areas. Similarly, the study of Mirza (2012) used manually prepared cadastral maps of 1940 for digitising parcel boundaries. In that study, cadastral maps were geo-referenced using satellite imagery but without incorporating physical field surveys and community participation, thus creating doubts on accuracy of produced cadastral maps.

The objective of the study is to develop a robust method to automate the digitisation of manual cadastral maps using geospatial technology. It focuses on an accurate identification of boundary marks using revenue record, PGIS, GPS field surveys and satellite imagery. The proposed methodology is expected to facilitate the auditing and validation of existing manually prepared cadastral maps in Pakistan.

Methodology

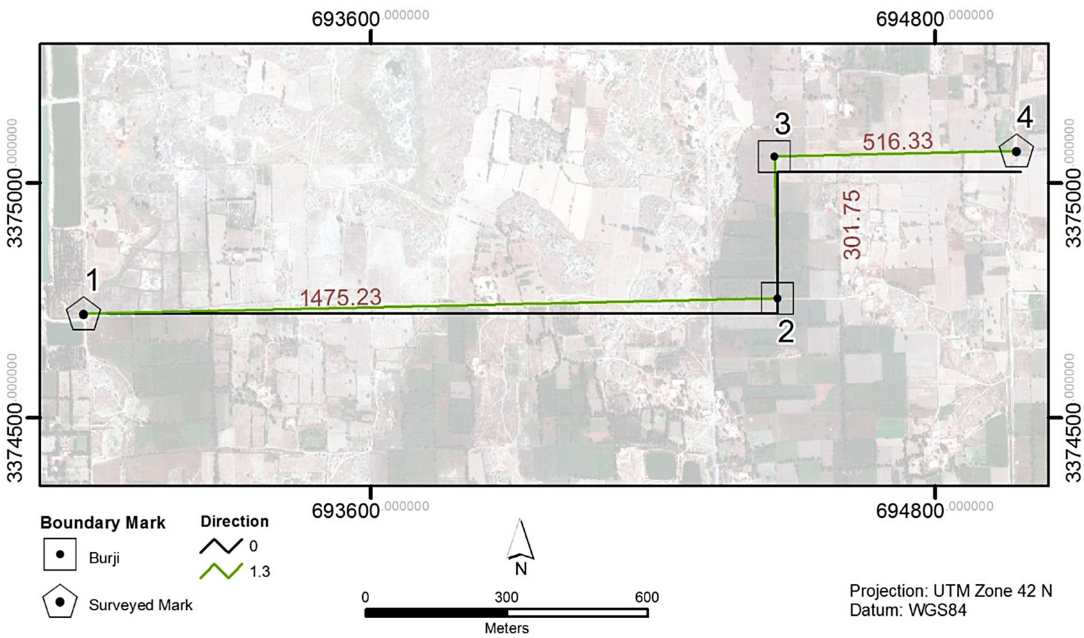
The proposed methodology for cadastral mapping through geospatial technology is similar to the one proposed by Tuladhar 2005; Prudhvi Raju *et al.*, 2008; Ali *et al.*, 2012; Sengupta *et al.*, 2013; Rao *et al.*, 2014. The methodology also incorporates the element of verification using physical surveys and high resolution satellite imagery. The proposed methodology is not a mere digitisation of cadastral maps or satellite imagery (Demir and Çoruhlu, 2008). Rather, it uses boundary marks to act as key information for automated construction of parcel geometry, along with satellite imagery as complementary

3 Location of a boundary mark in the study area, (top right corner inset shows zoom in view)

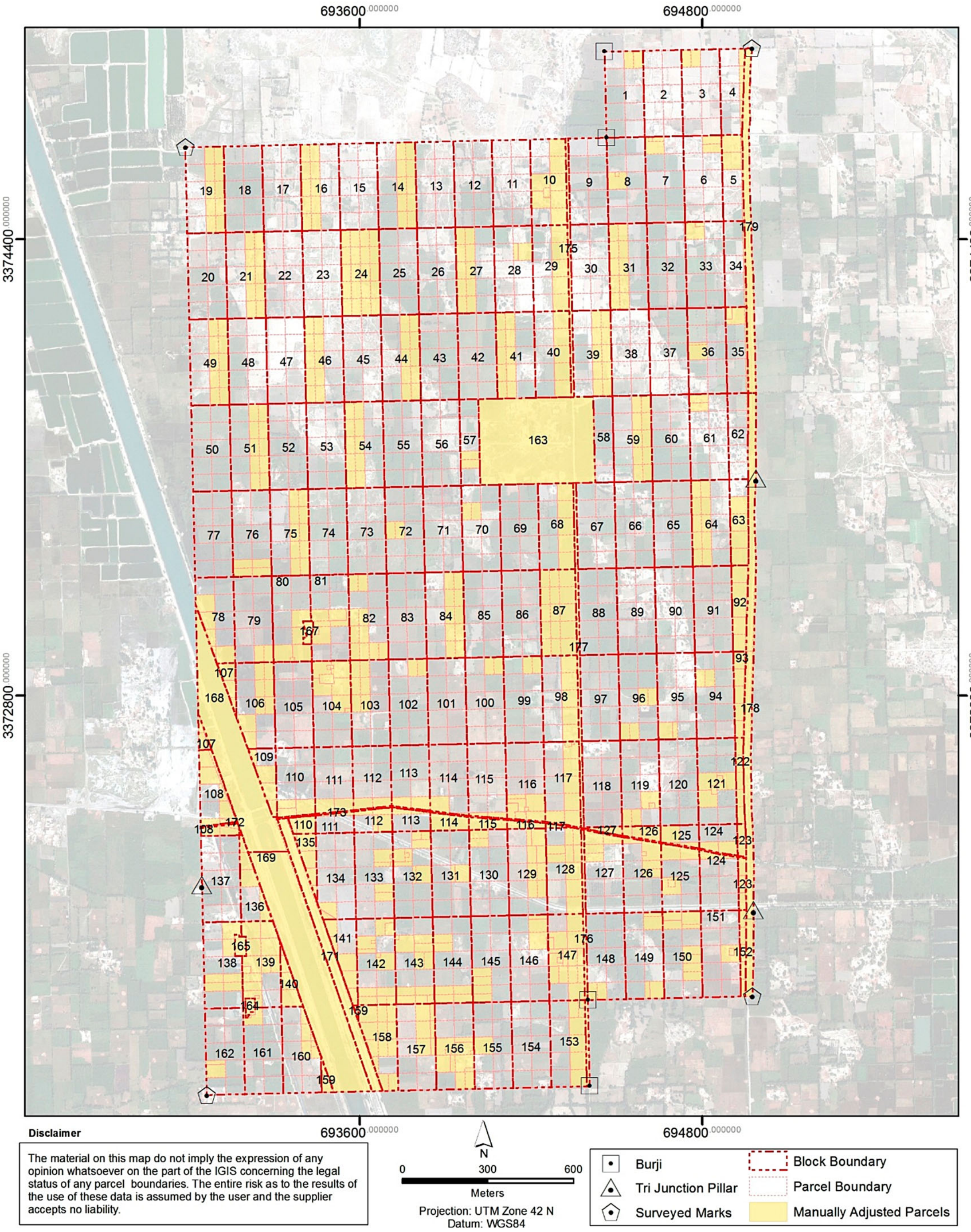
4 The displacement between the actual and GPS field survey location of boundary mark on satellite imagery. Courtesy of the DigitalGlobe Foundation

verification tool. The area chosen for study was selected due to its rectangular form since this study aims to present a good case for testing automated geometry construction for rectangular areas. The flow chart diagram of the methodology is shown in Fig. 1.

Scanned cadastral maps and field books obtained from the BOR were used as a major source of information. QuickBird ortho-rectified satellite imagery with sub-metre resolution having UTM projection system and WGS 1984 datum was used to synchronise the manual cadastral map into digital form. Moreover, unique parcel survey numbers were used which integrated both official and geospatially created records, to enable cadastral auditing. Discrepancies were evaluated by comparing



5 Connecting boundary marks using actual lengths and computed directional shift



6 Automated digitisation of block and parcel geometry along with manual adjustment

the field book records, manual cadastral maps and geospatially created parcel geometry.

Study area

Study area is a revenue estate naming *Chak* No. 154-ML which is situated in District Muzaffargarh of Punjab Province in Pakistan (Fig. 2). The area lies between 30° 27′ 32″ to 30° 28″ 35′ N and 71° 0′ 39″ to 71° 1′ 49″ E. Land settlement of study estate was done by the BOR in 1971–72 based on a rectangular system. A field survey on land settlement is conducted and measurements of each land parcel are recorded in a field book. The officially notified total estate area is 1604.04 acres. There are six parts of the cadastral maps of the study area and each part is prepared on a scale of 1:2500 (1 inch:40 Karam), as per field book measurements. The study area is generally a plane surface with minor sand dunes, with its elevation varying from 129 to 134 m. The area is divided into 179 blocks and 1824 land parcels, locally named as 'Khasra', numbered in a defined sequential order.

Identification of boundary marks

PGIS has successful applications in forest boundary demarcation (Sharestha, 2006) and cadastral mapping (Basiouka and Potsiou, 2012). The overall accuracy of cadastral mapping is dependent on the accurate

Table 2 Proposed parcel survey numbers system for Pakistan

Administrative level	Number of digits	Example
Level-I (Province)	2	32 (Punjab)
Level-II (District)	4	3230 (Muzaffargarh)
Level-III (Tehsil)	6	323003 (Kot Addu)
Level-IV (Union Council)	8	32300309 (Shasi Khan Munda)
Level-V (Estate)	10	3230030907 (Chak no 154-ML)
Level-VI (Block)	12	3230030907155
Level-VII (Parcel)	15	3230030907155010

Table 3 Calculated and notified estate areas and the comparative discrepancies

Estate area	Area (acres)	Discrepancy (acres)
Officially notified on field book	1604.04	0
Computerisation of field book record	1607.28	+3.24
Rectangular base on manual cadastral maps	1596.05	−7.99
Geospatially calculated	1595.73	−8.31

Table 4 Comparison of rectangular base and geospatially calculated area on six individual cadastral maps

Cadastral map	Rectangular base area (Acres)	Geospatially calculated area (Acres)
A-1	(170 + 9.75) 179.75	179.77
A-2	(167 + 17.97)184.97	184.45
A-3	(120 + 11.325) 131.33	131.51
B-1	300	300.00
B-2	400	400.00
B-3	400	400.00
Total area	1596.05	1595.73

identification of boundary marks (Lemmen, 2010). The role of PGIS becomes critical in accurately identifying boundary mark locations in cases where these are not physically present on-ground. PGIS helps to maintain overall accuracy of cadastral survey and mapping. Cadastral maps of the study area printed at a scale of 1:2 500 were consulted, with useful input from revenue officials and land owners. Once the participants were educated on how to read permanent features such as roads, settlements, canals etc. on the cadastral map, their collective input was helpful for on-ground identification of boundary marks. The boundary marks located on four corners of the study area were identified through PGIS. These boundary marks were further surveyed using a handheld Garmin eTrex GPS receiver (Annexure C). The GPS receiver had an induced error up to 10 m (Garmin, 2007). For automated digitisation of the parcel geometry and geo-referencing of cadastral maps, only four corner points were considered sufficient. Figure 3 shows the encircled boundary mark as identified physically on the ground through PGIS and surveyed using GPS.

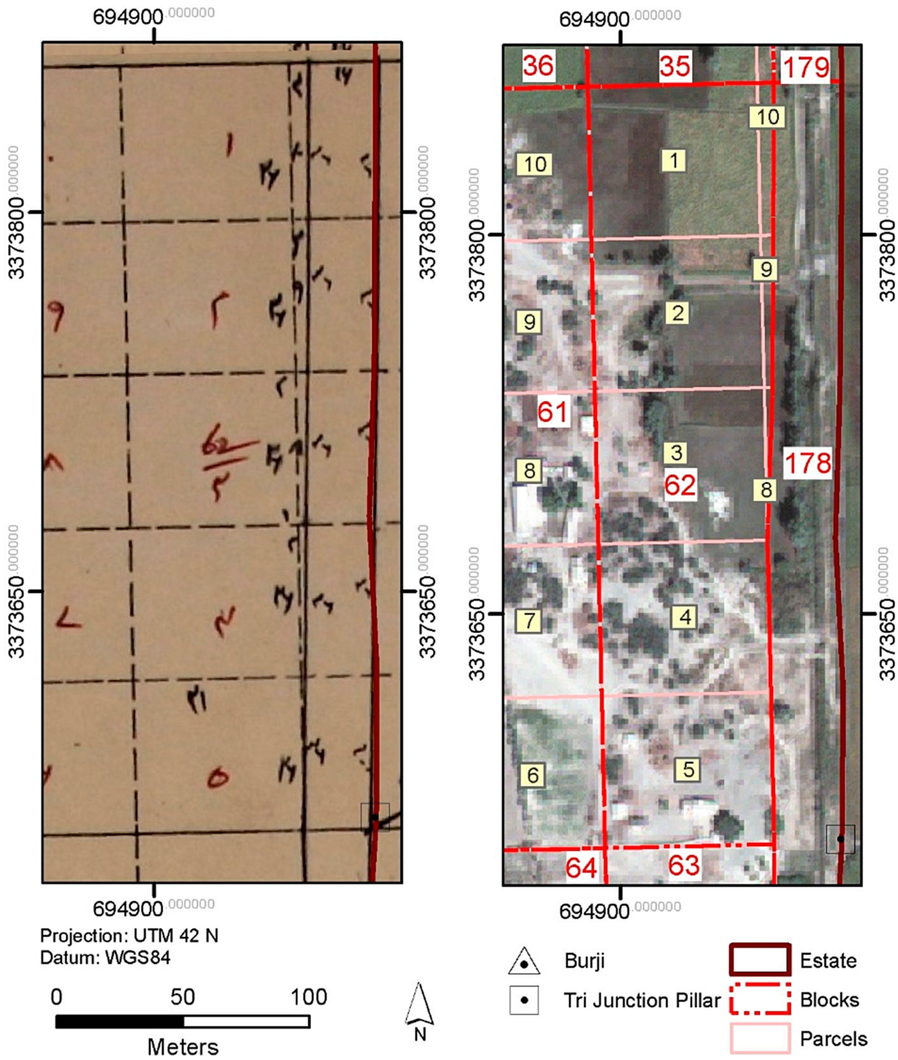
The above-mentioned boundary mark also identified on sub-metre satellite imagery. Both identified locations along with 5 and 10 m buffers is shown in Fig. 4. The visual interpretation on sub-metre satellite imagery revealed that GPS identified location is about 4 m displaced from the actual boundary mark location due to GPS induced error. There is also a possibility of error in identifying the mark on sub-metre satellite imagery due to ambiguity in exact pixel selection when pinpointing the mark on the image. For the sub-metre satellite imagery, the error range may extend up to 1–2 m.

Directional shift of parcel lines

According to official field book measurements, the distance between boundary marks 1 and 2 is 1475.23 m. A straight line could not perfectly connect these boundary marks (Fig. 5). When the directional shift of 1.3° (anticlockwise, obtained through trial and error) is added, the line exactly connected the boundary marks. Similarly, directional shift of 1.3° (anticlockwise) connected boundary marks 2 and 3 with given distance 301.752 m (180 Karam) and 3 and

Table 5 Blocks and parcels with significant area discrepancy

Serial Number	Block Number	Parcel survey number	Area (Acres): Computerisation of field book	Area (Acres): Geospatially calculated area	Discrepancy
1	98	6	0.50	0.85	+0.35
2	98	7	0.50	0.85	+0.35
3	98	8	0.50	0.85	+0.35
4	98	9	0.50	0.85	+0.35
5	98	10	0.50	0.85	+0.35
6	171	171	8.51	8.84	+0.33
7	136	1/3	0.01	0.29	+0.28
8	119	4	0.77	1.00	+0.23
9	135	9	0.51	0.74	+0.23
10	106	5	1.00	0.60	−0.4
11	178	178	14.23	13.67	−0.55
12	81	8	1.00	0.43	−0.57
13	34	6	1.00	0.10	−0.9
14	62	6	1.00	0.00	−1
15	62	67	1.00	0.00	−1
16	169	169	37.56	28.77	−8.79



7 Verification of missing survey numbers 62/6 and 62/7

4 as well. It was observed that the overall orientation of all the parcels in the estate has 1.3° anticlockwise directional shift along both X and Y-axis (Annexure D).

Cadastral geometry construction

After identification of boundary marks location and angular shift, a quick and easy cadastral geometry construction method was applied. Utilising such a method, digitisation of existing paper-based cadastral maps can be a laborious and time consuming exercise due to existing inaccuracies.

Automated approach

An automated and precise cadastral geometry creation is essential to quickly transform bulk of manual cadastral mapping data into digital form. The fishnet tool of ArcGIS has the capability to precisely draw automated grids. These require information about the origin, the Y-axis coordinates (to incorporate any directional shift) and location of the opposite point as well as the grid size (ESRI, 2012).

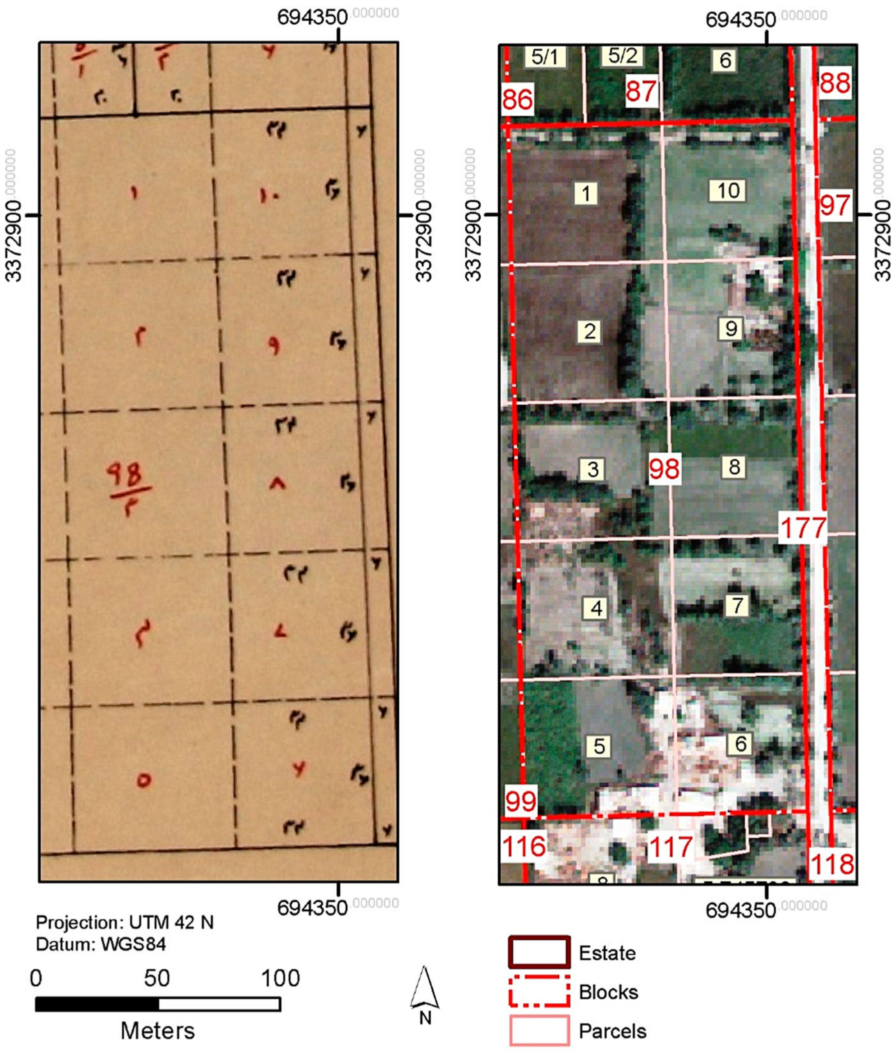
The precise location of the origin of the grid (693 064.76, 3 371 402.86), Y-axis coordinate (692 989.4, 3 374 723.59) and opposite point (695 105.6761, 3 375 068.1382) is obtained through integrated geospatial approach. The dimensions of the rectangular parcel are 67.056 × 60.3504 metres (40 × 36 karam) while that of a block are 134.112 × 301.752 m (80 × 180 karam).

Manual adjustment

The methodology/techniques require two types of manual adjustment in the land parcels and blocks. First adjustment includes (1) dividing them exactly into two parts and (2) dividing them based on given parcel measurements. The second type of manual adjustment in the estate was mostly due to roads, irrigation channels and settlements in the area. The manual adjustment of two equal parts was done simply by using the mid-point as a divider. The known measurement of individual blocks/parcels noted in the field book as well as cadastral maps were used for any adjustment of irregularities in the rectangular blocks/parcels.

Geo-referencing scanned cadastral maps

The cadastral maps were geo-referenced on the basis of the corrected boundary marks using 1st order polynomial (affine) transformation which preserves rotation, skewness



8 Verification of survey number 6–10 of block number 98

and differential scaling. This technique requires at least three boundary marks to shift the cadastral maps into their relative location on-ground (Iliff, 2000). Affine transformation was chosen since the parcels are rectangular shaped and affine transformation preserves parallel and straight lines (Brannan *et al.*, 2011). The parcel geometry created using field book measurements was overlaid on geo-referenced cadastral maps to verify and audit both datasets.

Proposed survey numbers

Currently, manual cadastral mapping has no digital database for the unique identification of survey numbers throughout the country. Survey numbers assigned to each parcel are unique only for an estate and are numbered in a way that is unsuitable for a digital database environment. In order to overcome this problem, this study proposes the use of administrative hierarchy for the unique identification of survey numbers as practiced in Malaysia and India (HARSAC, 2011; MGDI, 2014). Table 2 shows the different administrative levels and their proposed unique survey numbers.

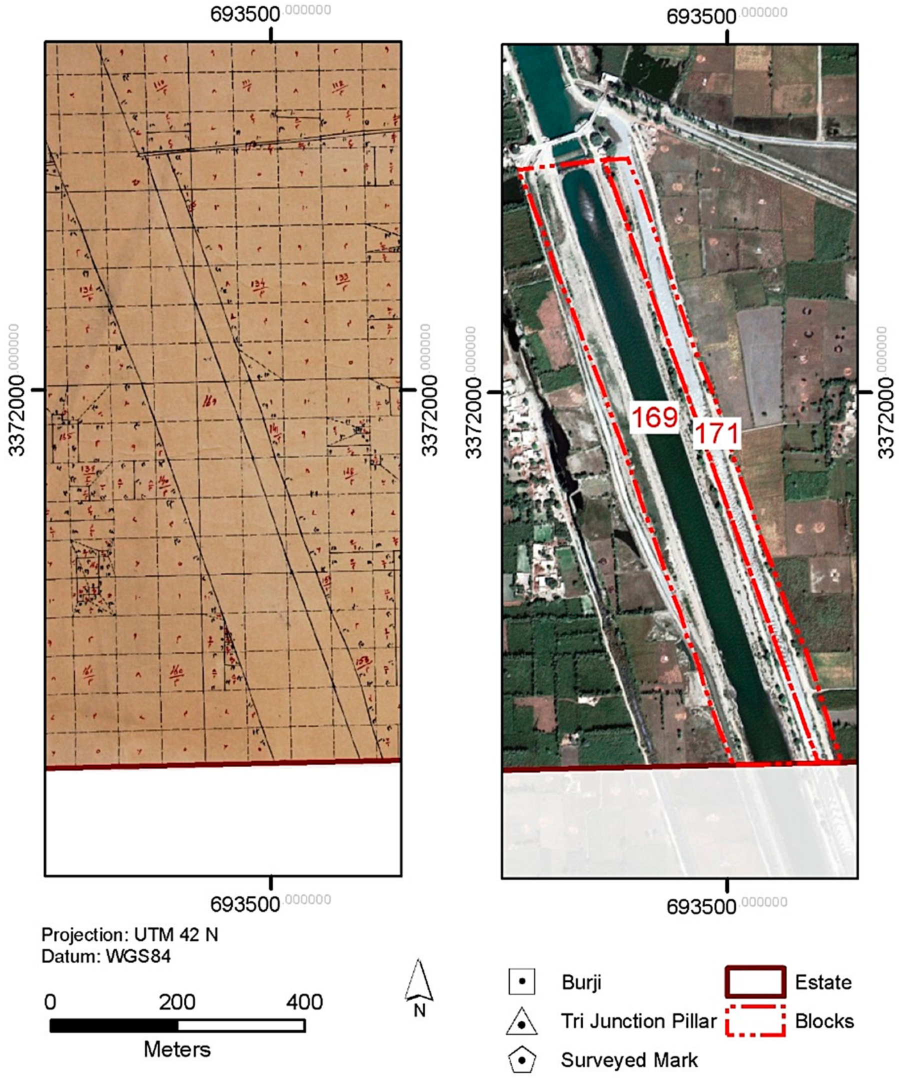
Cadastral audit and area calculation

Once the manual field book attribute data were entered in the database and parcel geometry along with its allied geo-database was constructed, a relationship between both datasets was created using the proposed 15 digits unique survey numbers. The one-to-one relationship between the two datasets was made use of to conduct a cadastral audit by comparing both. While the discrepancy in area is reported positive, the field book reported it as negative and over reported in comparison with the geospatially calculated area.

For the cadastral audit, four area calculations have been made, (1) BOR official notified total estate area, as mentioned on the field book, (2) area obtained through computerisation of field book entries of individual parcel records into a database system, (3) rectangular base area, obtained by calculating the total number of rectangles and their respected area on manual cadastral maps, (4) Geospatially calculated area, obtained through the automated digitisation of parcel geometry. The discrepancy in areas is considered significant if the difference is >0.2 acres and insignificant if less. Additionally, ownership records were also used to verify the results.

Results and discussions

The study has introduced an integrated geospatial approach for automated digitisation of parcel geometry



9 Area verification of block number 169 and 171

and its audit and validation. The use of satellite imagery, field book-based parcel measurements and PGIS helped in identifying boundary marks. There is a possibility of 1–2 metres shift in location of the boundary marks obtained through sub-metre satellite imagery and up to 10 m using handheld GPS.

Automated cadastral geometry

The outer boundary of the study area is of regular shape on three sides while it is irregular on eastern side due to the nearby irrigation channel. 62% land parcels of the study area are of regular shape and 38% are of an irregular shape (Fig. 6). About 17% of irregular-shaped parcels are subdivided into two equal parts, either vertically or horizontally, while rest of the 21% have random subdivision.

Estate area audit

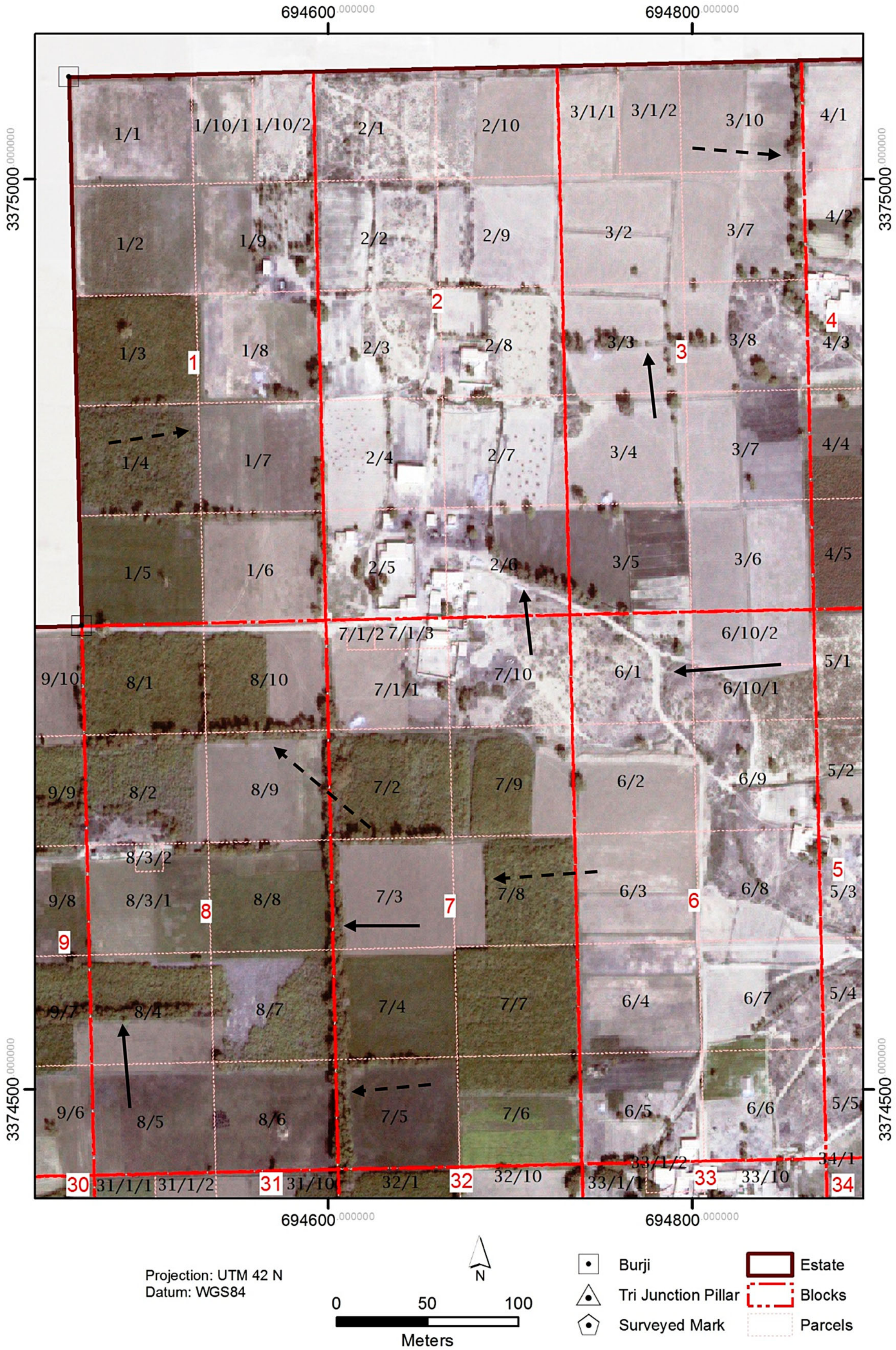
Total estate area officially noted on the field book is 1604.04 acres. Estate areas obtained from computerised field book records, rectangular based and calculated geospatially are shown in Table 3. These calculated areas do not match with officially notified areas and contain several discrepancies. Compared to officially noted field book area, a positive or negative discrepancy refers to over and under reported areas respectively.

Validation

Six individual cadastral maps consist of rectangular grids where each rectangle is equal to one acre land as shown in Fig. 1. Although the shape of rectangles was altered due to roads and canals, the total number of rectangles on a single cadastral map remained the same. A difference of only 0.32 acres is observed when comparing rectangular base area and geospatially calculated area on six different maps, as shown in Table 4.

Similar validation is performed at parcel level. It is observed that out of the 1823 land parcels investigated, around 6% have area discrepancy, out of which only about 1% can be considered significant [>0.2 acres (Table 5)].

Parcel level area discrepancy is confirmed using ownership records, scanned cadastral maps and satellite imagery. Blocks number 62, 98 and 169 have a discrepancy of more than 1 acre. For block number 62, two acres area is over reported in the field book against parcel survey numbers 62/6 and 62/7, which are missing from the cadastral map. The area and dimensions of eight (8) other parcels of this block are similar on the cadastral



10 Match and mismatch among actual and physical boundaries in a portion of study area

map and the field book. Input from revenue officials and land owners' along with satellite imagery data helped clarify that the adjacent parcel is an irrigation channel cutting into block number 62 (Fig. 7). These inputs helped identify field book errors which were duly confirmed through the ownership records (register).

Block number 177 is a 10.1 m (6 Karam) wide road which passes through block number 98 and reduces its five (5) parcels area. Demarcation of a road on the cadastral map and satellite imagery is shown on Fig. 8. The geospatially calculated area of each parcel of block 98 is 0.85 acres, confirmed from manual cadastral maps and PGIS, while in the field book it is reported as 0.5 acres each. Hence in 5 parcels, a total area of 1.75 acres is under reported in the field book. This was further confirmed from ownership records.

Table 4 above shows a discrepancy of −8.79 acres in block number 169 assigned to Muzaffargarh Canal due to the later construction of Thal Canal (a tributary from Muzaffargarh canal) for local irrigation and assigned a separate block number 171 (Fig. 9). 8.8 acres area of Thal Canal which was a part of Muzaffargarh Canal was given a new parcel number but not deleted from block number 169, thus presenting as duplicate areas in these two parcels. Both parcels are owned by the Irrigation Department.

Actual blocks/parcels vs physical field boundaries

While the legal or actual block and parcel boundaries are created on the basis of official field book measurements, the physical field boundaries in each parcel may not match due to customary agricultural practices and irrigation convenience. Figure 10 shows actual block and parcel boundaries and their corresponding physical boundaries on-ground. The similarity or contrast between actual and physical boundaries is shown with dotted and non-dotted arrows respectively.

Conclusions

Boundary marks serve as a base for accurate cadastral mapping in Pakistan therefore, recording their precise location and on-ground placement is critically important. PGIS proved very helpful for the initial identification of boundary marks on-ground and correlating their location on high resolution satellite imagery. It can further help in auditing and validation of land parcel areas and discrepancies. Although this study used a coarse resolution GPS receiver for identification of boundary marks, use of high precision GPS can significantly improve the process. Similarly, accuracy of the identification of boundary marks on satellite imagery will depend upon its spatial resolution. Full automation for the parcel geometry construction is not feasible due to irregular parcel boundaries.

The evaluation of cadastral maps and field books showed discrepancies due to the manual entry nature of land recordkeeping being used. The ground validation of geospatially calculated area and rectangular base area were almost the same, but had discrepancies with the field book entries. The problems in the field book were due to mismanaged manual data entries; mistakes were made during record updating procedures or when entries were manually copied into duplicate backup registers.

The methodology is valid for rectangular and square survey systems in plain areas with minimal effort and significant time saving. The application of geospatial technology and PGIS has proven to be an efficient method for transforming existing paper-based cadastral maps into their geospatially enabled digital form. The use of Differential GPS is further recommended for the precise boundary marks survey in the country.

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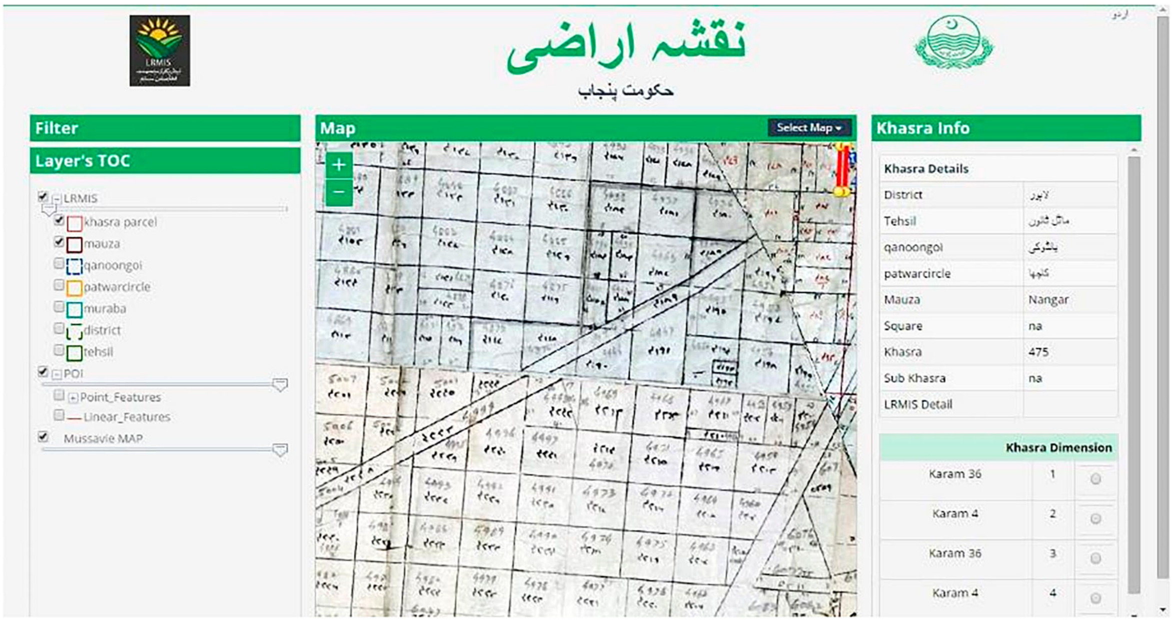
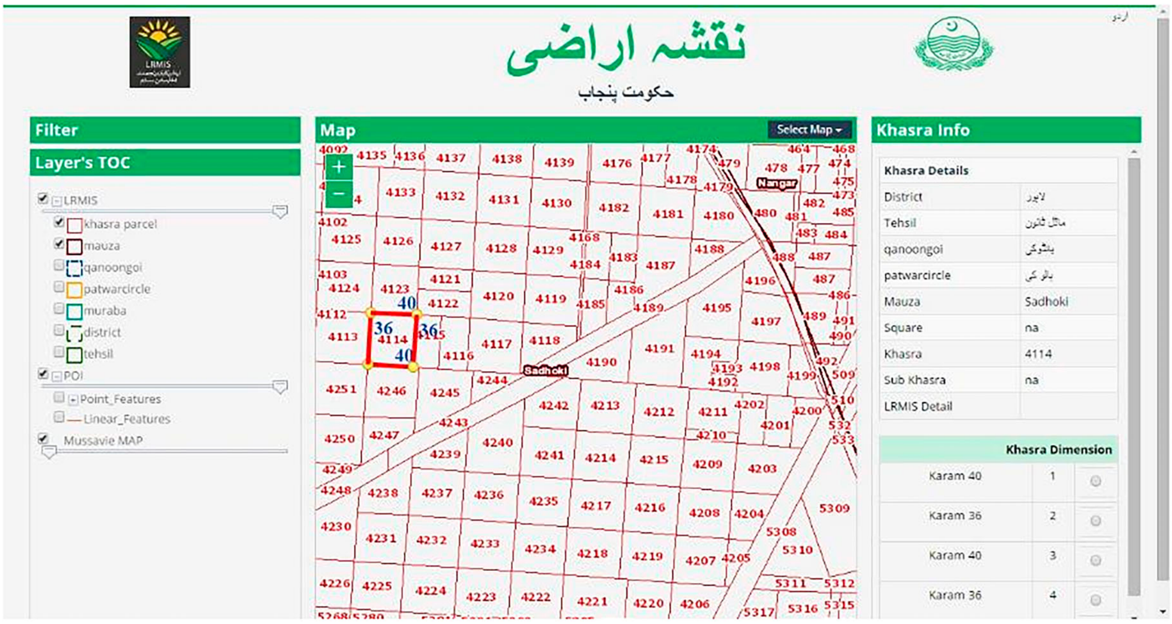
Annexure

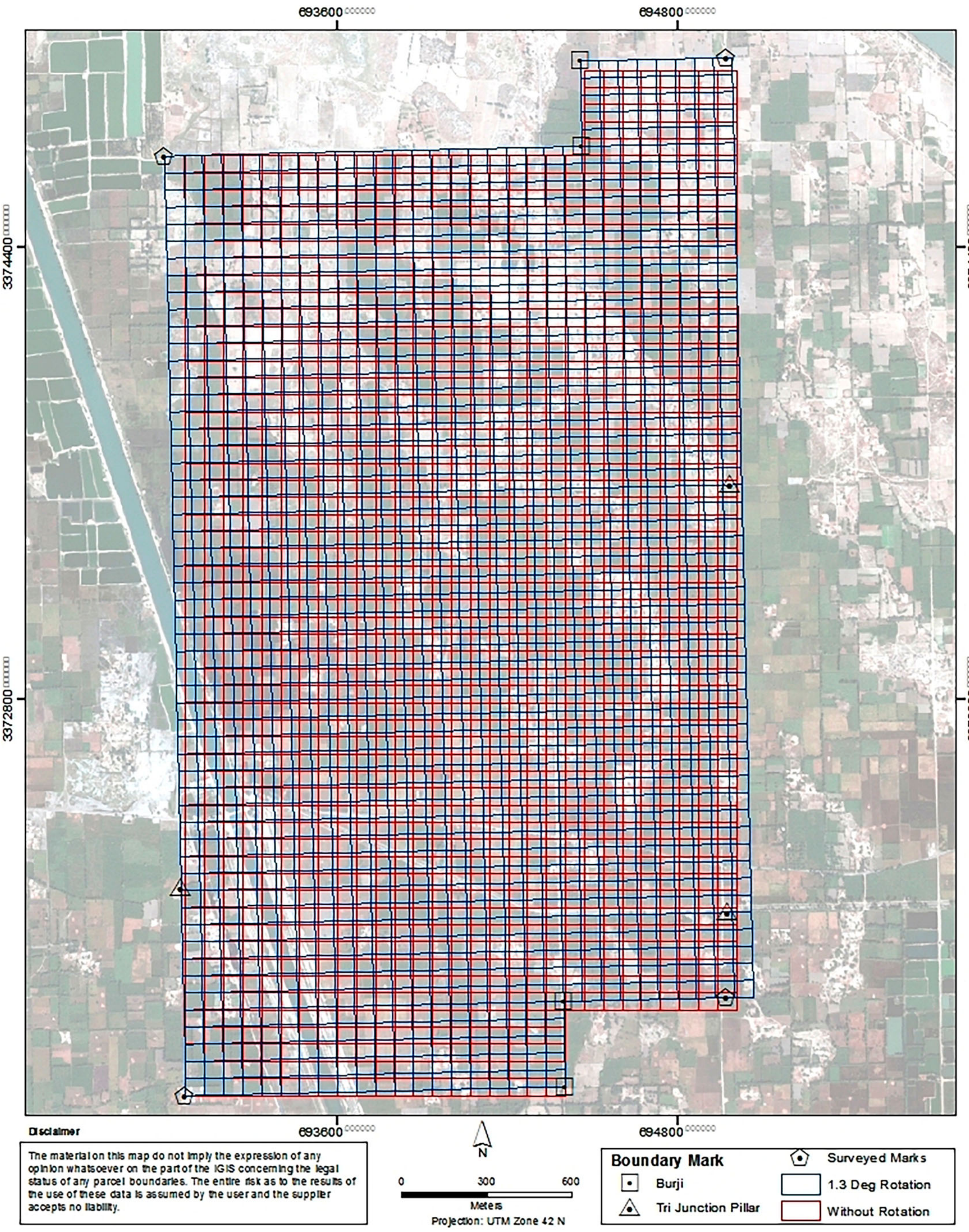


A: Skewness and mismatch in paper-based cadastral maps in Lahore district (Source: http://lrma.punjab-zameen.gov.pk/).



B: Digitisation of erroneous data of Lahore district (Source: http://lrma.punjab-zameen.gov.pk/).

C: Garmin eTrex handheld GPS receiver for boundary marks survey.



D: The parcel grid created through fishnet tool with and without having directional shift of 1.3.