Statistical Data Collection Methodologies of Irrigated Areas and Their Limitations: A Review

ALI AJAZ*, POOLAD KARIMI², XUELIANG CAI², CHARLOTTE DE FRAITURE² AND MUHAMMAD SALEEM AKHTER³

¹Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, OK, U.S

²Land and Water Development for Food Security, Water Science and Engineering, IHE Delft Institute for Water Education, Delft, the Netherlands

³Department of Civil and Environmental Engineering, The University of Auckland, New Zealand

ABSTRACT

Inconsistencies in the statistical datasets of irrigated areas at the national level could have considerable implications for policies developed for food and water security. Remote sensing can address this issue, however, dubieties of its reliability inhibit its protagonist role. Methods that integrate both remote sensing based and statistical datasets seem expedient, and they are more likely to be acknowledged by the policymakers. Therefore, it is important for scientists to know the basis and limitations of statistical datasets which originate at the country level. Data collection methodologies of irrigated areas were reviewed for seven Asian countries, namely China, India, Pakistan, Bangladesh, Nepal, Indonesia, and Thailand. Factors causing the uncertainties in data, and the limitations of data collection methodologies were highlighted. Also, an irrigation density distribution analysis was conducted to understand the relation of spatial spread pattern of irrigated areas and uncertainty in their statistical records. It was found that irrigated areas statistics are mostly based on the information originating from water user associations and farmers, which is either self-reported or it is collected through interviews during surveys and censuses. The main causes of discrepancy were lack of resources to frequently enumerate the irrigated land, inconsistency in the data collection methodologies, unaccounted secondary crops, illegal and unregulated water use, and bureaucratic and political constraints. Irrigation density distribution analysis showed that the largely scattered irrigated areas might be prone to lack of comprehensive and frequent enumeration. Furthermore, dense irrigation regions might have potentially unrecorded irrigated areas where temporary or supplementary irrigation arrangements are made by the marginal farmers.

KEY WORDS: irrigation survey; agricultural census; discrepancy in data; irrigation density distribution; remote sensing.

Correspondence to: Mr. Ali Ajaz. E-mail: ali.ajaz@okstate.edu

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INTRODUCTION

70% of the global irrigation-equipped areas are in Asia, and they support a population of 4.42 billion people, expected to reach 5.2 billion by 2050 (Food and Agriculture Organization of the United Nations (FAO), 2014a; Mukherji et al., 2009). Such a significant rise in population will put a huge burden on the irrigation infrastructure to fulfil growing food and economic needs, which can be achieved by intensification and the remaining possible expansion of irrigated agriculture (Faurès et al., 2002; Alexandratos and Bruinsma, 2012). A 30–40% increase in water demand has been predicted for Asia by 2050, with 80% of water use dedicated to irrigation (Sato et al., 2017). Irrigated agriculture, which is already overloaded with the burden of improvement in water productivity and yields, also has to contend with other stakeholders for its share of water resources, i.e. industry and households (Asian Development Bank (ADB), 2016). In addition, climate change will be a contributing factor to the challenges that the irrigation sector will be facing in the near future (Krishnamurthy et al., 2015; Kadiresan and Khanal, 2018). Reliable information on irrigated areas is crucial for analysing agricultural water use, crop water productivity and, subsequently, for devising interventions that can help achieve food and water security goals (Döll and Siebert, 1999; Portmann et al., 2010; Karimi et al., 2012). Furthermore, unrealistic policies may be developed because of uncertainty in such data (Droogers, 2002; Kendy et al., 2003).

Irrigated areas datasets can be divided into three main categories. The first category is the statistics that originate at the national and sub-national level, and they are disseminated by the countries (FAO, 2018). FAO also receives these statistics from the member countries, and data repositories are maintained at various platforms such as FAOSTAT, AQUASTAT, and Global Maps of Irrigated Areas (GMIA) (Droogers, 2002; Siebert *et al.*, 2005). The second category is the remote-sensing (RS) based datasets, which include land cover maps (e.g., US Geological Survey (USGS), 2000; Global Land Cover (GLC), 2003; GlobeCover, 2010; European Space Agency (ESA), 2015, etc.), and the RS studies dedicated to map irrigated areas (e.g., Frolking *et al.*, 1999; Alexandridis *et al.*, 2008; Thenkabail *et al.*, 2009a; Siddiqui *et al.*, 2016; Ambika *et al.*, 2016, etc.). The third one combines both country-based statistics and RS-based datasets to develop maps of irrigated agriculture (e.g., Pervez and Brown, 2010; Zhu *et al.*, 2014; Salmon *et al.*, 2015; Meier *et al.*, 2018, etc.).

The first two categories of irrigated area datasets have been reported with various uncertainties, which also limit the precision of the irrigated area statistics obtained using the third approach. The statistical datasets carry information gaps between the area actually irrigated and the extent of land officially recorded under irrigation (Ambika *et al.*, 2016), which could be due to the high cost associated with data collection, lack of human resources, weak institutional infrastructure, obsolete methodologies, etc. (FAO, 2016a, 2018). In addition, these datasets are

disseminated by countries and FAO after passing through multiple bureaucratic and political layers, which makes the statistics prone to manipulations (Bastiaanssen, 1998, Nickum, 2003, Thenkabail *et al.*, 2009b). Remote sensing, on the other hand, faces accuracy issues due to limited ground truthing, variation in spatial resolutions of input datasets, low accuracy in humid-areas due to cloud coverage and lack of background information, and distinctive paddy mapping (Frolking *et al.*, 1999; Siebert *et al.*, 2005; Xiao *et al.*, 2005; Biggs *et al.*, 2006; Thenkabail *et al.*, 2007; Zhu *et al.*, 2014). Furthermore, problems faced in irrigated area mapping due to supplemental irrigation, fractional estimation of irrigation in pixels, and small and dispersed irrigation have been highlighted by Droogers (2002) and Jin *et al.* (2016).

In the near future, the progress to overcome the limitations of the statistical datasets would be comparatively slow (FAO, 2018), whereas the new developments in remote sensing would keep broadening the horizon for mapping and monitoring of irrigated agriculture (Houborg and McCabe, 2018; Chen *et al.*, 2018; Taghvaeian *et al.*, 2018). This would open up opportunities for RS to complement the shortcomings of statistical datasets. However, according to the United Nations Global Working Group (UNGWG) (2017), the paradigm shift from traditional statistics to RS-based estimations will not be simple for the countries with their already established statistical system. In addition to the organizational resistance to change, issues associated in general with RS-based datasets i.e., validity and uncertainty, also slow down the process to move forward. In view of these intricacies, the third category of irrigated areas mapping, which combines the statistics and RS approach, seems promising as it could assist the countries to upgrade their data collection systems. Also, it would be perceived as a tool by policy-makers to help them reduce the discrepancies in national statistics. Therefore, it is important for the researchers to have an understanding of the country-specific data collection methodologies, which are the backbone of the statistical datasets, and their limitations as well. Also, to know the regions with higher potential discrepancy and its possible reasons is instrumental.

The objective of this paper is to review the irrigated areas' data collection and reporting methodologies of seven Asian countries (China, India, Pakistan, Bangladesh, Nepal, Indonesia, and Thailand), and to highlight their limitations along with the possible reasons of discrepancies. In addition, an irrigation density distribution analysis was conducted using GMIAv5 map (Siebert *et al.*, 2005) with the purpose of linking the uncertainty in data with the spatial variation in density of irrigated areas.

INFORMATION SOURCES

Seven Asian countries were selected from East, South, and Southeast Asia (Figure 1), which varied in terms of their irrigated areas extent. This selection was representative to review the reporting methodologies of area wise large and small countries. Some of the limiting factors while

selecting the countries were the availability and access to their reporting methods, language barriers, and delayed or no response from the country officials for getting the desired information.

Figure 1. Seven Asian countries selected for the study

Irrigated areas' data collection methodologies were amassed from the online sources that include annual reports and yearbooks published by agricultural, irrigation, water resources, and statistics departments of the selected countries. Also, the publications of agriculture and irrigation census and surveys, and land use surveys were accessed. In addition, questionnaires were also sent to the relevant officials of the selected countries who work in various departments (e.g., irrigation, agriculture, etc.). These questionnaires mainly inquired about the modus operandi that a particular department exercises to record and verify the information of irrigated area in their domain. Also, the information was sought regarding the irrigation water fee, enumeration of ground-water fed areas, and informal irrigation. The response received from the officials was incorporated subsequently as personal communication in this paper.

IRRIGATION DENSITY DISTRIBUTION

The spread pattern of irrigated areas in a region could be a contributing factor in the discrepancy of the data, especially the under-estimation issues. For example, largely dispersed irrigated agriculture in a region or a country might hamper frequent enumeration by the authorities, and

possibly cause data glitches. Also, the countries with a large proportion of its irrigation being practiced in dense irrigated areas might have unreported irrigation (Meier *et al.*, 2018) due to several reasons such as uncertain water supplies and irrigation water-use outside the command areas. Therefore, the irrigation density distribution analysis can provide valuable information to comprehend the spatial spread pattern of irrigated agriculture in a country.

GMIAv5 was used for this analysis, which is a geographic information system (GIS) based spatial distribution of the statistical irrigation data, and it is mainly retrieved from censuses, surveys, and reports of FAO, World Bank, and irrigation associations (Siebert *et al.*, 2013). According to Siebert *et al.* (2005), fraction of unit cell area equipped for irrigation is defined as irrigation density. Since GMIAv5 provides the area equipped for irrigation (AEI) in terms of density (percentage of AEI in unit cell; size 0.0833°), this information can be categorized to cognize the general spatial distribution of irrigation density. Though the process of allocating the irrigation densities to cells in different countries was not completely uniform (Siebert *et al.*, 2013), yet it may provide a realization of some potential issues that countries could be possibly dealing with to control the quality of their irrigated area statistics. Other irrigated area maps can also be analyzed with respect to irrigation density; however, only GMIA map was used for this purpose since several studies have used it as a base map for statistical data inputs. ArcMap 10.5 by Esri was used for data processing and developing the maps.

The GMIAv5's percentage AEI pixel values range from 0 to 100 for most of the countries. These values were divided into three categories and the AEI for the corresponding pixels was summed. The categories ranged from 1 to 30%, 31 to 60%, and 61 to 100%, which were denoted as small, medium and densely clustered irrigated areas, respectively (Table I). Furthermore, to the best of our knowledge, there are no set rules to categorize the density distribution on the basis of percentage AEI. The irrigation density distribution patterns of the selected countries were discussed linking them to the potential causes of discrepancies in irrigated area statistics.

Table I. Categories of irrigated areas summed on the basis of GMIAv5 AEI irrigation density

Irrigation density category	Percentage area equipped for irrigation
Small clustered irrigation	1–30
Medium clustered irrigation	31–60
Densely clustered irrigation	61–100

China

Ministry of Water Resources' irrigated area statistics (MoWR, 2006), which are known as Effective Irrigated Area (EIA), are generally based on the data that originates from irrigation projects and the irrigation stations in townships, and this data is usually collected by observing the fields which were irrigated (Nickum, 1995; Yao *et al.*, 2015; Personal Communication, 2015a). Notice that EIA does not include the irrigated pastures, orchards, and forests (Zhu *et al.*, 2014). The National Bureau of Statistics' (NBS) irrigated area estimates (NBS, 2017) are based on self-reporting from basic production units to NBS and agriculture ministry (Nickum, 2003). The irrigated area statistics of agricultural census of 2006 (NBS, 2008) were based on the land-use survey, which was conducted using topographic maps and aerial photography (Ministry of Land and Resources (MLR), 2007).

Nickum (2003) pointed towards the possibility of over-estimations in MoWR statistics for the purpose of departmental esteem and priorities in the budget. Moreover, these statistics follow a regional to national hierarchy before the dissemination, and they seem to be prone to artificial adjustments. Furthermore, the lands that are irrigated from the seepage water of canals are not included in the irrigated area statistics. In addition, the farmers, which follow NBS' self-reporting mechanism, might under-report the irrigated areas with the intention of seeking a concession in water fee. The irrigation water withdrawal quotas could also be exceeded (Thevs *et al.*, 2015) without reporting the areas irrigated with the excess water.

The causes of potential discrepancies in the statistics can be associated with the spatial variation in irrigation density as well. The irrigation density distribution analysis showed that China has 25.1 Mha (million hectares) of AEI, which comes under the category of small clustered irrigation, where the irrigation density ranges from 1 to 30% (Figure 2). The small clustered areas consist of 40% of the irrigated agriculture and it is spread over 274 Mha of land, with a major presence all across the north to south on the eastern half of the country. Maintaining a reasonable quality of irrigated land data in these areas could be quite challenging from the administrative point of view, especially while relying on traditional statistical methods (Biggeri, 2002). Furthermore, the medium clustered irrigated area is 23.7 Mha, and the dense irrigated areas have an extent of 13.1 Mha, with a significant concentration in East China.

Figure 2. Irrigation density distribution in China (Data source: FAO-GMIAv5-AEI; Siebert et al., 2005)

India

Agricultural ministry in India maintains a well-detailed dataset of irrigated areas which includes means of irrigation and crops irrigated (Directorate of Economy and Statistics (DES), 2001). Ninety-one percent of the reported area lies under the states which maintain land records, where village accountants keep the registers of land-use and crop statistics (DES, 2012; National Informatics Centre (NIC)-a, n.d.), and pass on this information to revenue department for taxation. This data is either collected by visiting the farms or it is based on information provided by the farmers. States lacking the land record systems are covered by sample surveys with a frequency of five years, whereas information from remote mountainous areas is usually based on subjective estimates (Ministry of Statistics and Program Implementation (MSPi), 2018a, b). Irrigated areas data, during the agriculture census of 2010-2011, was collected through input survey which was conducted in 7% sample villages of each sub-administrative unit (tehsil) (NIC-b, n.d.). Minor irrigation census of 2006-2007 and 2013-2014 was conducted in India to collect the irrigation related statistics (e.g., irrigation potential created and utilized etc.) particularly for minor irrigation schemes such as tube wells, tanks, surface flow and lift schemes, and ponds, along with medium and large-scale irrigation scheme as well (MoWR, 2014). These irrigation censuses relied on the village records for public schemes data, whereas enumeration was conducted for minor irrigation schemes by interviewing their owners together with physical verification (MoWR, 2017).

The irrigation density distribution analysis showed the share of small, medium and densely

clustered areas as 16.4, 16.5, and 29.0 Mha, respectively (Figure 3). Small clustered irrigated areas are spread almost all over the country, over an area of 162 Mha. A large presence of these areas is in those states that were mentioned by Thenkabail *et al.* (2009b) for causing the discrepancy in the statistics due to unreported fragmented minor irrigation, namely Madhya Pradesh, Andhra Pradesh, and Maharashtra. Also, the states with no land-record system (e.g., north-eastern states) have such areas in abundance, which could be really challenging to report accurately. The states in the foothills of Himalayas have most of the medium and densely clustered irrigated areas, which are equipped with both canal and groundwater irrigation and predominantly use groundwater pumps. In these regions, under-reporting of irrigated land belonging to small and marginal farmers is likely to be occurring as the majority of these farmers buy water and do not own pumps, thus could be over-looked during minor irrigation enumeration (Srivastavaa and Kumar, 2006; Kumar *et al.*, 2013). Meier *et al.* (2018) mapped the irrigated agriculture by integrating RS and GMIA and marked missing areas in India mainly situated within dense irrigated regions already present in statistics. They found the absence of minor irrigation practices from statistics responsible for this (e.g., supplemental irrigation, temporary irrigation wells, etc.). Also, the irrigated area statistics could have discrepancy due to issues such as under-reporting of the irrigated canal command area in order to avoid water tax (Shah, 2011). Additionally, MSPI (2018c) reported the discrepancies in the village records and highlighted the overburdening of village accountants as one of the possible reasons.

Figure 3. Irrigation density distribution in India, Pakistan, Bangladesh, and Nepal (Data source: FAO-GMIAv5-AEI; Siebert *et al.*, 2005)

Pakistan

Provincial agriculture departments maintain the irrigated area statistics including the irrigation sources (Pakistan Bureau of Statistics (PBS), 2018). The basis of these statistics is village record registers, which are furnished by the revenue department's village accountants/clerks (PBS, 2011). The irrigation and revenue departments work in collaboration at village level, where the irrigation booking clerks physically visit the area and pass on this information to revenue department to collect irrigation fees (Tahir and Habib, 2001). Complete enumeration method is followed, and each irrigation booking clerk covers approximately 1200 to 2000 hectares of the cultivated land (Ul Haq, 1998). In addition, southwestern parts of the country are usually covered with subjective estimates; however, information from tribal areas and northern regions is not included in the datasets. The agricultural census of 2010 was based on sample enumeration technique and village accountants were mainly responsible for data collection. Door-to-door interviews were conducted in all regions including unsettled areas, southwestern and northern regions as well (PBS, 2010). Furthermore, the irrigated area statistics were published along with farm size, percentage of cultivated area in land equipped for irrigation, mode of irrigation, crop season, and access to perineal and non-perineal canal water.

Irrigation density distribution analysis showed that Pakistan has 1.46 Mha of small clustered irrigated areas, 3.02 Mha of medium clustered, and 12.3 Mha irrigated area is densely clustered (Figure 3). The small clustered irrigation is spread over 17 Mha; mostly in northern mountainous and remote south-western regions. There is a lack of information on irrigation activities in these areas (Government of Pakistan (GoP) and International Union for Conservation of Nature (IUCN), 2003), also the enumeration activities are usually insufficiently funded (FAO, 2008). Thus good quality irrigated area statistics are less likely to be expected from these regions. Besides, the potential practice of subjective estimates in remote areas can possibly compromise the reliability of information regarding areas actually irrigated. Relatively well spread network of agriculture and irrigation department in eastern and south-eastern parts of the country (medium and densely clustered irrigated areas) is presumed to maintain reliable statistics. However, their irrigated agriculture statistics might be prone to under-reporting due to influential landlords and the socio-political dynamics of irrigation (Mustafa, 2001). In addition, with the recent development in irrigation sector in Pakistan, the rain-fed lands are now being irrigated with pressurized irrigation systems, which may not be recorded as irrigated land in administrative reports (Personal Communication, 2017).

Bangladesh

Bangladesh Bureau of Statistics' (BBS) irrigated areas data (BBS, 2012) is based on sample enumeration, where households are interviewed for collecting the required information (FAOa,

2007). The information on irrigated areas is disseminated by means of irrigation and crop type. Canal irrigated areas, included in this dataset, are based on the information provided by the water users associations (Personal communication, 2015b). The agriculture census of 2008 included the irrigated areas information, which was collected by sample enumeration. Interviews were conducted for data collection and post-enumeration checks were also made for validating the information. Furthermore, the irrigated areas data was disseminated in different categories such as tenancy, farm size, and source of irrigation (BBS, 2008). Minor Irrigation Survey of 2005 was conducted exclusively for collecting irrigation related information by two agriculture development agencies and agriculture extension department. The information collected was based on statements from farmers who own water pumps, and personal judgments of enumerators (Ministry of Agriculture (MoA), 2005). Along with the irrigated area statistics, the minor irrigation survey's dissemination also included number of pumps, power source, and type of pumping unit (Bangladesh Agricultural Development Corporation (BADC), 2010).

The irrigation density distribution in Bangladesh is highly skewed towards medium and densely clustered irrigation with an area of 2.5 and 1.93 Mha, respectively (Figure 3), whereas the small clustered irrigated areas have an extent of 0.6 Mha, which is distributed over 4.4 Mha of land, and mostly situated in northeastern, southeastern, and southwestern regions. Essentially, these are the regions where surface water irrigation is mostly practiced using low-lift pumps, in order to extract water from creeks, river, and ponds (FAO, 2014b). The irrigated agriculture is dominated by groundwater in Bangladesh, and this is practiced mainly in northwestern and central regions, where most of the medium and densely clustered irrigated areas are located. From data quality point of view, the small clustered irrigation seems more prone to discrepancies. However, the chances of inconsistency during sample surveys of groundwater-fed densely clustered irrigated areas could also not be ruled out. The major challenges could be the massive number of small farms in Bangladesh as almost 98% farmers own area less than 3 ha (Palash, 2017), and the unregulated groundwater use (Qureshi *et al.*, 2015). Moreover, FAO (2014c) has reported concerns about the quality of irrigated area statistics in Bangladesh and highlighted the data gaps. Some of these gaps are caused due to inconsistency in data sampling frames, department wise variation in the definition of irrigated land, and the methodological differences.

Nepal

Department of Irrigation (DOI) statistics mainly rely upon the reporting from water user associations of command area (Personal communication, 2015c), and surveying for assessing the actual area irrigated is not commonly practiced. In addition, only those farmers managed irrigation systems (FMIS) are included in the statistics of irrigated area which receive assistance from the DOI. It is important to mention here that schemes consisting of an area less than 25 ha in mountainous regions and less than 100 ha in plain lands are not eligible for DOI's assistance. The

statistics are disseminated by categorizing the type of management such as surface irrigation schemes (farmers and DOI managed), groundwater irrigation schemes (shallow and deep wells), and traditional irrigation (DOI, 2007). Irrigated area statistics of agricultural census 2011 were collected by sample enumeration method (Central Bureau of Statistics (CBS), 2013). Interviews were conducted to collect data of irrigated area and source of irrigation. Living standard survey (2010-2011) also included the information on irrigated land, the survey was based on sample enumeration, and the farmers were interviewed for the data (CBS, 2012).

Nepal has 0.63 Mha of small clustered irrigated areas, which are located over 9.03 Mha of land, almost all over the country (Figure 3). The medium and densely clustered irrigation have an area of 0.46 and 0.08 Mha, respectively, and they are mostly concentrated in southern parts of the country. Being expanded over a large area, the small clustered irrigation could be difficult to enumerate for a periodic update of irrigated area records. Moreover, Kayastha (2012) reported several factors affecting the data quality during agriculture census such as lack of qualified human resources in remote regions, mismatch in timing of enumeration and cropping season, and the reluctance of households to share accurate data in order to avoid any additional taxes.

Thailand

Agriculture ministry's Office of Agriculture Economics (OAE) statistics are based on annual surveys, and these surveys use interviews as a tool to collect raw information from the farmers (FAO, 2010; OAE, 2015). The Royal Irrigation Department's (RID) data collection process relies on the reports from the farming community as water user associations convey their need for water on the basis of area. (RID, 2008; Rattanatangtrakul, 2017; Personal communication, 2018).

Irrigation density distribution analysis showed that small, medium, and densely clustered irrigated areas have extent of 2.25, 2.11, and 2.06 Mha, respectively (Figure 4). The small clustered irrigation is spread almost all across the country over an area of 22.8 Mha, and the majority of medium and densely clustered areas are located in central Thailand. It is important to mention here that all three irrigated areas categories in Thailand are heavily dominated by surface water use (92% of the total area equipped for irrigation). Surface water irrigation systems have been reported for illegal extractions by non-command area farmers (Sinclair *et al.*, 2013), and the irrigated area is over-estimated by the reservoir authorities for ensuring their budgets (Blake, 2012). The interviewing techniques to collect agricultural data by sampling in Thailand have been reported to be inaccurate and less reliable by Japan International Cooperation Agency (JICA) (2007). Though the interviews based data collection method could be an effective tool, the time lapse, and human memory to remember the facts could potentially decrease the accuracy of the enumeration processes (FAO, 1996). It was found that Irrigation water has been a free utility in the past, which could potentially abate the importance of irrigated areas information in national

statistics. Although Thailand has taken the initiatives towards water pricing (Molle, 2001), the payment mechanism between RID and water user groups is yet to be finalized (Personal Communication, 2018).

Figure 4. Irrigation density distribution in Thailand and Indonesia (Data source: FAO-GMIAv5-AEI; Siebert *et al.*, 2005)

Indonesia

Agriculture ministry's irrigated area statistics are compiled on the basis of administrative records prepared by local agricultural service offices (MoA, 2010, 2015). Agriculture department and national statistical agency work in collaboration for collecting agricultural statistics. Their data collection mechanism is complete enumeration that is based on field observations and statistics provided by farmers (Margono, 2013). The disseminated reports carry the information of irrigated and non-irrigated paddy; however, information regarding the irrigated area for other crops is usually not included. Land area utilization statistics, published by the national statistical agency, included irrigated and non-irrigated paddy area in wetlands (Badan Pusat Statistik (BPS), 2013). These statistics were collected from agricultural extension offices of every sub-district in the country, and most probably based on administrative reports. The data collection methodology of Directorate General of Water Resources was not available online, nonetheless, Personal Communication (2015d) revealed that a decentralized system works at the district level for collecting the data of irrigated areas from water user associations. The frequency of data collection is two months and farmers' knowledge of their area under irrigation is the main data source.

Furthermore, field verifications are not a very common practice. Noticeably, the agricultural census of 2013 had no explicit information regarding irrigated areas of crops.

Indonesia has a considerably dominant proportion of small clustered irrigation with an area of 3.71 Mha, which is spread over 52.5 Mha of land, and mostly located in Java, Sumatra, and in some southern and northern parts of Kalimantan and Sulawesi (Figure 4). The medium and densely clustered irrigated areas have an extent of 1.68 and 1.33 Mha, respectively, and they are predominantly located in Java and in few parts of Sumatra. Since Indonesia's irrigation infrastructure is mainly focused on paddy, there is a higher probability of discrepancy in irrigated areas statistics of crops such as maize, soybean, and other commercial plantations. It is important to mention here that no water fee is associated with irrigation supply in Indonesia, which could be one of the factors causing potential discrepancies in the data.

CONCLUSION

Statistical data collection and reporting methodologies of irrigated areas were reviewed for seven Asian countries in order to find their limitations and potential causes of discrepancies. These countries include China, India, Pakistan, Bangladesh, Nepal, Indonesia, and Thailand. In addition, Irrigation density distribution was analysed to understand the connection of discrepancies in data with the spatial spread pattern of irrigated agriculture at the country level. It was found that statistical datasets of the irrigated areas are mostly based on information received or collected from the farmers such as self-reporting from water users associations and interviewing the individual households in villages. Furthermore, the self-reported information is not necessarily verified by the authorities. Sample enumeration is widely practiced for collecting irrigated area information along with other agricultural statistics. Moreover, expert estimates usually have substantial input in the irrigated area statistics originating from the remote areas.

The significant potential causes of discrepancies in statistical datasets of irrigated areas are as follows:

- lack of resources to periodically update the records;
- unreported areas in densely clustered irrigated regions due to supplemental irrigation or temporary irrigation arrangements;
- inefficient enumeration methods in largely scattered irrigated areas;
- primary importance given to major crops while overlooking other irrigated crops;
- illegal use of irrigation water from canals;
- unregulated groundwater exploitation;
- bureaucratic and political constraints causing under and overestimation issues.

Since irrigated area statistics estimated using both statistical datasets and remote sensing appears to be expedient, scientists should be aware of the basis of information originating from the countries and the possible reasons of uncertainty as well. In order to ensure better agricultural water management, and to develop realistic policies for water and food security, precise information of irrigated land is inevitable. Therefore, the causes of data discrepancies are definitely needed to be addressed by the countries by allowing necessary modification in policies, legislation, infrastructure, and by embracing technological advancement.

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Table

Table I. Categories of irrigated areas summed on the basis of GMIAv5 AEI irrigation density

Irrigation density category	Percentage area equipped for irrigation
Small clustered irrigation	1 to 30%
Medium clustered irrigation	31 to 60%
Densely clustered irrigation	61 to 100%