Innovative methodology of demand responsive approach for large-scale water supply and sewerage/on-site sanitation projects in developing countries using participatory GIS with high resolution satellite imagery

Shozo Mori, Ihsanullah, Akira Koizumi, Chinatsu Maeda, Kazuhiro Asada, Yoshiaki Yokota and Masayuki Mori

ABSTRACT

International discussions on the demand responsive approach (DRA) started in the mid-1990s because past supply-driven approaches had led to the failure of many water supply and sewerage/on-site sanitation (WS&S/OS) projects in developing countries (DCs). DRA has already been adopted in many WS&S/OS projects targeting a certain rural or poor urban area(s) by using various demand assessment techniques such as participatory rapid appraisal (PRA) to select optimum technical options. However, adoption of DRA in large-scale urban WS&S/OS projects (covering various areas of different socio-economic groups with different needs) has been relatively delayed. Recently, the participatory geographic information system (PGIS) has emerged as an effective method of PRA, and high resolution satellite imagery (HRSI) has become commercially available. This paper presents a PGIS-based visual area categorization of different income groups using HRSI as a key for expediting the adoption of DRA to large-scale projects in DCs. This paper proposes an innovative pro-poor methodology of DRA for large-scale urban WS&S/OS projects. The methodology focuses on the improvement of multistage sampling in a household sample survey to plan mixed services suitable for various groups. The results of a partial application of the methodology in Pakistan are also presented.

Key words | demand responsive approach, developing countries, high resolution satellite imagery, participatory GIS, sewerage, water supply

Shozo Mori (corresponding author)
Chinatsu Maeda
Kazuhiro Asada
Yoshiaki Yokota
Masayuki Mori
Nihon Suido Consultants Co., Ltd.,
22-1, Nishi-Shinjuku 6-Chome,
Shinjuku-ku,
Tokyo,
Japan 163-1122
Email: *mori_s@nissuicon.co.jp*

Ihsanullah
Peshawar University,
Peshawar,
Pakistan 25120

Akira Koizumi
Tokyo Metropolitan University,
1-1 Minami-Osawa,
Hachioji-shi,
Tokyo,
Japan 192-0397

ACRONYMS AND ABBREVIATIONS

CVM	contingent valuation method
DANIDA	Danish International Development Agency
DCs	developing countries
DFID	Department for International Development, United Kingdom
DRA	demand responsive approach
ESRC	Economic and Social Research Council
FINNIDA	Finnish International Development Agency
GIS	geographic information system
HRSI	high resolution satellite imagery
IRC	IRC International Water and Sanitation Centre
JICA	Japan International Cooperation Agency
NGO	Non-governmental organization
ODI	Overseas Development Institute
PGIS	participatory geographic information system
PRA	participatory rapid appraisal
RP	revealed preference
WEDC	Water, Engineering and Development Centre
WELL	The WELL Resource Centre for Water, Sanitation and Environmental Health
WSP	Water and Sanitation Program
WS&S/OS	water supply and sewerage/on-site sanitation

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WTP	willingness to pay
USAID	United States Agency for International Development

INTRODUCTION

International discussions on the demand responsive approach (DRA) started around 15 years ago because past supply-driven approaches of international aid agencies had led to the failure of many water supply and sewerage/on-site sanitation (WS&S/OS) projects in developing countries (DCs). 'There is plenty of documented evidence of past projects which have failed because they did not take into account the expressed needs and demands of the target population' (Parry-Jones 1999). The World Bank and many bilateral donors (DFID, USAID, FINNIDA, DANIDA, etc.) have already adopted DRA in many WS&S/OS projects that target rural areas or selected poor urban areas within large cities in order to improve the effectiveness and sustainability of the projects (WSP & IRC 2003). The results of adopting DRA (for selecting an optimum technical option(s) and introducing community-based management of WS&S/OS facilities) in rural and poor urban areas have been reported in many documents (WSP & IRC 2003). However, adoption of DRA has been less successful in large-scale urban WS&S/OS projects covering various communities and neighbourhoods with complicated social structures in DCs.

Large-scale urban WS&S/OS projects that target different income groups simultaneously have several advantages over projects targeting only poor urban areas. The advantages include the possibilities of: (1) encouraging effective cross-subsidies between the poor and the rich; (2) optimizing the balance of investment for WS&S/OS (e.g. installing a water supply system and a sewerage system together to avoid serious environmental problems due to increased wastewater discharge); and (3) attracting large-scale capital investment. Moreover, domestic water supply, sewerage and on-site sanitation often need to be planned simultaneously to maximize health benefits in DCs, especially for the urban poor (DFID 1998; Mori 2000; Mori & Koizumi 2000).

For these reasons, this paper proposes an innovative pro-poor interdisciplinary methodology of DRA for large-scale urban WS&S/OS projects in DCs to enhance the efficacy of projects for the urban poor without limiting possible combinations of WS&S/OS services. The realization of DRA in large-scale urban WS&S/OS projects requires more complicated considerations than those required for projects in rural areas or pre-selected poor urban areas. Residents of different income groups in a city usually live in separate neighbourhoods and have different needs. Low income groups can be further subdivided geographically, for example, into different ethnic groups receiving different services and expecting different improvements. The realization of DRA in large-scale projects also requires an interdisciplinary team of engineers, financial experts, social experts, public participation facilitators and so on. However, in many urban WS&S/OS projects in the past, lack of coordination between engineers and social experts significantly hindered the realization of DRA (Bos 2001). The interdisciplinary team has to establish good internal coordination by sharing information and knowledge on the complicated geographical variations that intersect different income groups from socio-economic and engineering aspects.

Recently, the participatory geographic information system (PGIS) has emerged as a participatory planning method. High resolution satellite imagery (HRSI) has also become commercially available worldwide. Since 2002, potential applications of PGIS and HRSI for WS&S/OS projects have been researched from interdisciplinary perspectives (Mori 2003). This paper presents a PGIS-based visual area categorization of different income groups using HRSI as a key for successfully adopting DRA for large-scale WS&S/OS projects in DCs. First, this paper reviews past methodological developments regarding DRA, PGIS and HRSI which form the foundation in this methodology of DRA for large-scale urban WS&S/OS projects. After an explanation of the new methodology, this paper highlights some results from the partial implementation of the methodology in Karachi, Pakistan, in 2006.

PAST METHODOLOGICAL DEVELOPMENTS

Demand responsive approach

In the past, rapid population growth in urban areas in DCs led international aid agencies to adopt supply-driven approaches that strongly emphasized the construction of new water supply and sewerage facilities, with considerably less attention given to the sustainable management of these services (DFID 1998). Consequently, many of these facilities broke down or fell into disuse once the external support came to an end (DFID 1998; Deverill *et al.* 2002a). It is clear that WS&S/OS projects and programmes will fail to be sustainable if they do not meet the expressed needs and demands of the target population (Davis & Whittington 1997). For this reason, DRA is needed in urban WS&S/OS projects (to provide different services for different neighbourhoods or households, depending on their expressed demands) without adopting a city-wide blueprint based on universal norms (Parry-Jones 1999).

Some engineers may argue that in most previous urban water supply and sewerage projects, projection of water demand of a target population was calculated from estimated future per capita water consumption. However, this argument does not mean that those projects have been demand responsive in terms of providing an optimum mix of different service options that meet the different needs of various groups. An example of mixed water supply services is: (1) continuous supply through house connections for high income areas, accompanied by significantly increased water charges; (2) intermittent supply of longer duration through house connections for middle income areas, without increasing water charges; and (3) shared connections using yard taps or water kiosks for low income groups, with subsidized water charges. An example of mixed sewerage and on-site sanitation services is: (1) conventional sewage collection system for densely populated high and middle income areas; (2) a low-cost sewage collection system for densely populated low income areas; and (3) septic tanks or twin leach pits for thinly populated areas. One option of a low-cost sewage collection system is the simplified sewerage system known as ‘condominial sewerage’. These simplified sewers can be laid in the front yard, under the sidewalk or inside the back yard and connect one household directly to adjoining households so that the total pipe length is minimized. An important point in developing a new methodology of DRA for large-scale urban projects is how to make these kinds of mixed WS&S/OS services more demand responsive while being more technically and financially feasible.

Demand assessment is central to designing a demand-responsive project. Currently, there are three main demand assessment techniques available: revealed preference (RP), contingent valuation method (CVM) and participatory rapid appraisal (PRA). RP is an indirect assessment that examines current behaviours such as the price paid to water vendors and the time taken to fetch water. CVM is a technique that asks people directly how much they would pay for improved WS&S/OS services in the future through household surveys. PRA includes participatory planning tools such as focus group discussions, participatory mapping and small non-random surveys. Each demand assessment technique has strengths and weaknesses. For example, RP is relatively economical, but it is not reliable when a wide variety of service options are available. CVM can quantitatively assess demands for a variety of possible improvements; however it is expensive, time consuming and not participatory but extractive. PRA is quick, flexible and cost-effective, but it has difficulty in gathering quantitative data.

In reality, there is a need to use a combination of different demand assessment techniques at different stages of a project cycle (DFID 1998; Parry-Jones 1999; Deverill *et al.* 2002b). Since 2002, there appears to be little discussion on combinational uses of different demand assessment techniques. However, Alison Wedgwood led a discussion on conceptual and practical challenges for DRA including effective combinational uses of different demand assessment techniques at the ESRC Seminar on Access, Poverty and Social Exclusion in 2005 (ODI 2005). The four key steps of DRA discussed in this seminar have been integrated into the new methodology of DRA proposed in this paper. Concurrently, the Water, Engineering and Development Centre (WEDC) in the UK has developed a new strategic marketing approach to water services for urban areas in DCs (Sansom *et al.* 2004). This approach has many aspects in common with DRA as well as new commercial aspects. Unfortunately, the methodology proposed in this paper has not yet incorporated the new aspects of their marketing approach.

Participatory GIS

In DCs, water and wastewater utilities have been increasingly adopting geographic information systems (GIS) to perform day-to-day operations, maintenance and customer services. Utilities can also use a GIS database when conducting hydraulic analysis for the facility planning and basic design of pipeline improvements. Since the mid-1990s, PGIS, which integrates GIS and PRA, has been increasingly used in DCs for rural development, resource management and urban community development (McCall 2008a, b). However, past applications of PGIS used in the selection of WS&S/OS service options in urban areas could not be identified.

PGIS is based upon one of the most powerful visual PRA techniques, known as participatory mapping. One example of participatory mapping for an urban WS&S/OS project in a DC is the empowerment of local people experienced through the mapping of their community for water and sanitation in Dar es Salaam, Tanzania (Gloeckner *et al.* 2004). In participatory mapping, perceptual maps (e.g. of natural resources, property status and existing problems) are created by local people in order to incorporate their environmental, socio-economic and cultural perceptions into planning without the significant expense of gathering data. Compared with data compiled by outside specialists, local environmental knowledge, captured in a perceptual map, is comprehensive and of outstanding quality (Cinderby 1999). In order to integrate these perceptual maps in a GIS environment where data accuracy is of primary concern, some kind of geographically referenced base map (e.g. topological map, land plot map, aerial photograph or HRSI) has to be utilized when adopting PGIS. By adopting PGIS, local knowledge can be effectively drawn onto print-outs of a base map and then digitized into a GIS database with reasonable spatial accuracy. PGIS can integrate conventional spatial data on natural and socio-economic environments and infrastructure with unconventional perceptual information based on local concerns and knowledge.

High resolution satellite imagery

HRSI can be used as an effective base map for PGIS. HRSI can extend the possibilities of PGIS in terms of the level of public participation, the accuracy of expressed perceptions, and the simplicity and affordability of base map preparation.

In conventional practices, base maps usually utilized in GIS databases are topographical maps which include rivers, mountains, roads and buildings, etc. In the past, a topographical map was usually created from many aerial photographs. The use of aerial photography has serious limitations regarding the limited coverage area of an aerial photograph, flying restrictions imposed upon sensitive areas such as military bases, the delivery time of data and so on. Fortunately, commercial HRSI of sub-metre resolution has recently become a powerful substitute for aerial photography. The resolution of commercially available satellite imagery has been dramatically improved as follows: 10 m in 1998 with SPOT-4, 82 cm in 1999 with IKONOS-2, and 46 cm in 2009 with WorldView-2. HRSI of 1 m or less in resolution can be used to identify houses and small paths. The homes of rich people usually appear larger than the homes of poor people on HRSI. The use of HRSI in the participatory mapping of PGIS is very effective for encouraging public participation because the participants can easily identify their neighbourhoods, including their own homes. The use of HRSI as a base map also provides high positional accuracy to the perceptual maps created with PGIS. In addition, HRSI is significantly cheaper than aerial photography covering the same area size with similar resolution and accuracy. The direct use of HRSI as a base map can dramatically reduce the cost and time of base map preparation.

PROPOSAL FOR A NEW DRA METHODOLOGY

Overall flow of the proposed methodology

This paper proposes a new pro-poor DRA methodology which adopts PGIS with the use of HRSI for improving demand-responsiveness of large-scale urban WS&S/OS projects in DCs. Figure 1 illustrates the overall flow of the methodology in a typical project cycle, which starts by setting HRSI as a base map of GIS that covers target areas.

The new methodology incorporates the four key steps of DRA, which were discussed in the ESRC seminar in 2005, through a new combinational use of the three types of existing demand assessment technique (RP, PRA and CVM). The four key steps are: Step 1, to assess existing coping strategies; Step 2, to assist with the design of technical and management options; Step 3, to enable households to select preferred services (to which they are able to

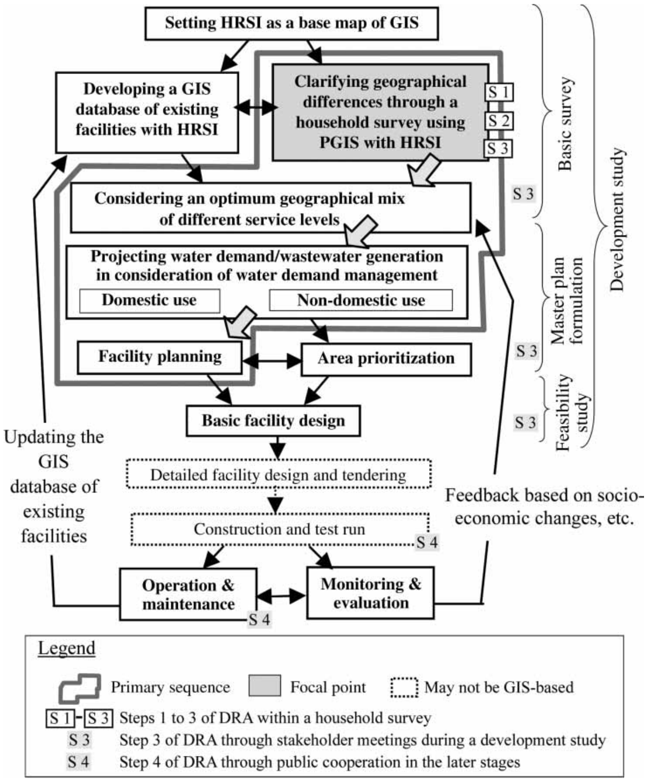


Figure 1 | Flow of the new methodology of DRA in a project cycle.

contribute); and Step 4, to facilitate the introduction and continuous use of the services (ODI 2005).

The primary sequence of the methodology shown in Figure 1 includes three key steps (out of the four) of DRA. The primary sequence starts from the clarification of geographical differences in socio-economic conditions and preferred services over different target areas during the period of the basic survey. The clarification is conducted through a sample survey of households using PGIS with HRSI in order to facilitate the selection of an optimum geographical mix of different WS&S/OS services. This PGIS-based household survey is later elaborated upon as the key discussion point of this paper. The optimum geographical mix of different services should be planned by an interdisciplinary expert team based on the household survey results, which are geographically referenced on the HRSI. The planned mix of different services should be presented with the HRSI in stakeholder meetings (which may include stakeholder meetings required for environmental impact assessment) for further discussion and consensus formulation. The primary sequence continues onto the quantitative projection of future water demand/wastewater generation for domestic and non-domestic water uses. This projection takes some of the results from the household survey into consideration. The proposed DRA methodology also provides a mechanism to incorporate the policy of water demand management in the projection of future domestic water demand, which is quite important especially for the areas suffering from severe water scarcity. As a result of the primary sequence, the improvement and expansion of WS&S/OS facilities for mixed services can be planned as part of a master plan.

Other than the primary sequence, this methodology, as seen in Figure 1, includes the development of a GIS database of existing WS&S/OS facilities using HRSI during the period of the basic survey. In DCs, WS&S/OS projects usually face difficulties in collecting information on the existing WS&S/OS facilities because of the limited availability of documents and drawings on existing facilities. The same HRSI used for the household survey can significantly assist the staff of a water utility to recall and locate existing water pipes and/or sewers in the development of a GIS database. The DRA methodology utilizes the developed GIS database for the facility planning of mixed WS&S/OS services and the selection of priority areas. It can also be utilized for the basic design of pipeline facilities during the feasibility study period. The GIS database should be continuously updated for the operation and maintenance of facilities and for the monitoring and evaluation of the project.

Household survey method using PGIS with HRSI

Prior to this research, there had been limited progress in creating a methodology that systematically and effectively reflects the results of a household survey for the optimum development of urban WS&S/OS facilities. The delay in applying DRA to large-scale urban projects was partly due to a lack of discussion between engineers, social experts and economists (Bos 2001). However, the biggest obstacle seems to be the ineffective geographical referencing of socio-economic data collected in past household surveys. For example, statistical results of a household survey comparing several administrational districts are often not very useful to engineers in understanding the conditions of various poor communities within each district. Social experts conducting household surveys may argue that it is not possible to survey the conditions of each poor community because their geographical boundary is often vague in urban areas. For these reasons, a new method of household survey using PGIS with HRSI (the focal point shown in Figure 1) is proposed in this paper to enhance effective use of household survey results for better planning of WS&S/OS facilities. The flow of the new method of household survey is illustrated in Figure 2.

As seen in Figure 2, the proposed method for the household survey can be divided into three stages: [1] participatory preparation; [2] field implementation and data entry; and [3] analysis and presentation of the household survey results. The participatory preparation stage of the household survey includes: (1) preparation of an optimal sampling design using PGIS with HRSI as a new PRA method; and (2) preparation of a questionnaire through focus group discussions using HRSI as another PRA method. The preparation of an optimal sampling design is explained in detail below. The contents of the questionnaire can include: (1) RP-related questions for revealing existing coping strategies of various groups; (2) questions illustrated with service option ladders (often used for PRA) or a matrix of possible combinations of WS&S/OS services (an example of this matrix [Mori 2003] is shown in Figure 3); and (3) CVM-related questions asking about willingness to pay (WTP) for improved services.

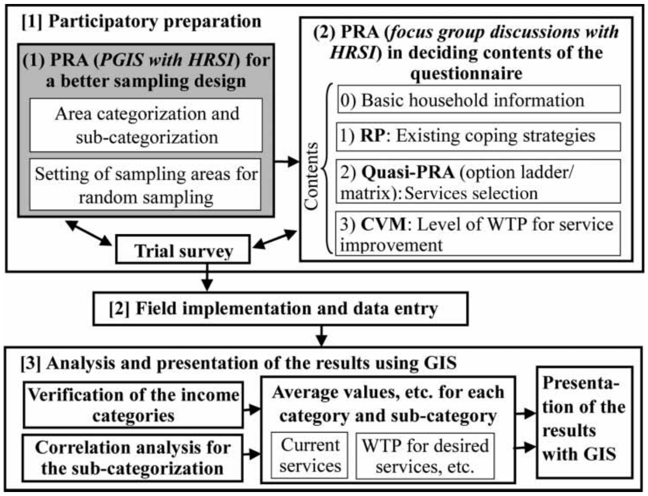


Figure 2 | PGIS-based method of household sample survey.

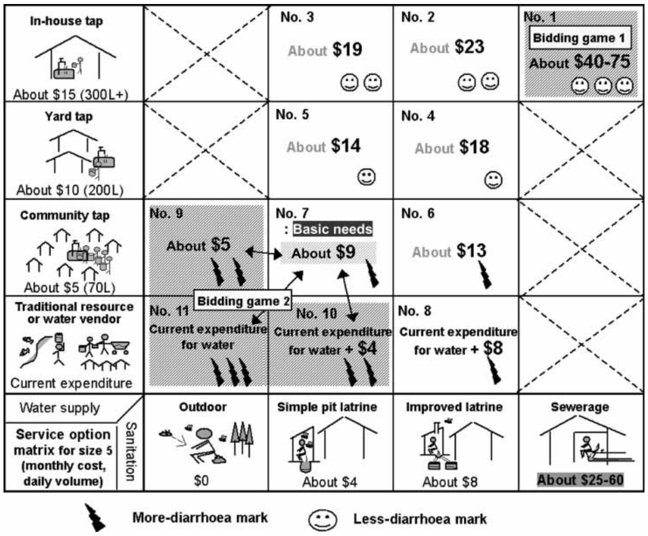


Figure 3 | Example of service option matrix of WS&S/OS services.

Preparation of a better sampling design

Figure 4 shows two examples of geographical categorization which can be used in a multistage sampling for a household survey.

Households' demand for better services differs significantly depending on their income level and purpose of water usage such as domestic use or commercial use. Therefore, as shown in Figure 4, it is better to categorize the target areas geographically by income level and land use in order to utilize the results of household survey effectively for the planning of mixed service levels. This kind of area categorization is also important in a large city for prioritizing areas

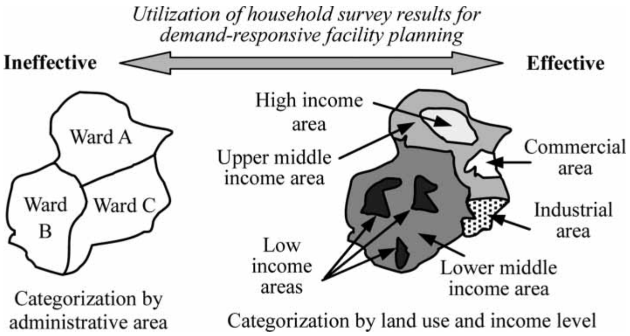


Figure 4 | Effective area categorization in a sampling design.

that require immediate improvement and for upgrading WS&S/OS services area by area within a limited budget. However, the differences in average income levels among areas and the geographical boundary of each area where households have a similar income level (hereinafter referred to as 'income group area') are usually not well reported in past studies in DCs.

For these reasons, a PGIS method is used in the proposed methodology in order to categorize target areas easily and effectively for a better sampling design. The proposed PGIS method is a participatory mapping of different income group areas and land uses based on local people's understandings (enhanced with the help of HRSI) and visual interpretation of different income group areas shown on the HRSI.

The examples of HRSI in Figure 5 show clear differences in appearance (land use, plot size, density, streets and vegetation) amongst residential areas of different income groups in Karachi, Pakistan. The dominant types of dwelling in each income group area can also be recognized on HRSI. Therefore, as seen in the example of Figure 6, a visual interpretation of HRSI can be used for area categorization by land use and income level.

Participation of local people is quite important in improving the categorization process since there are sometimes areas that are difficult to categorize by their appearance on HRSI only. Moreover, through this PGIS exercise, the amount of verification work on the ground required for the area categorization can be dramatically reduced. Participants in this exercise can be representatives from low and other income groups, local consultants on the project, staff of the water utility, officials from local government agencies, members of local NGOs and so on. During the area categorization process, quantitative income range or the average income of each income group area may be vague. However, the categorization can be reviewed and clarified later, in terms of the range and average of household incomes in each category, by analysing the results of the household survey.

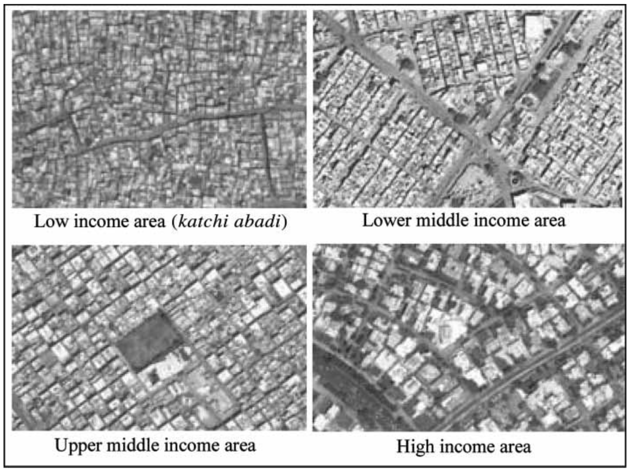

Low income area (*katchi abadi*)
Lower middle income area
Upper middle income area
High income area

Figure 5 | Apparent differences between different income areas.

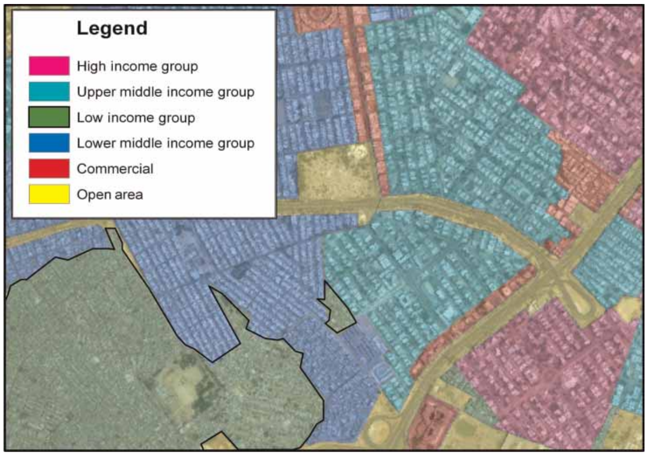


Figure 6 | Example of area categorization in Karachi using HRSI.

In many DCs, the proportion of low income groups within the total population of a large city is usually quite large. Low income areas in a large city often have significant differences between them in terms of existing service conditions and the demands for better services, even though their areas may look quite similar on HRSI. Therefore, sub-categorization of low income areas is often required to effectively understand differences amongst low income areas. The sub-category of low income areas is also quite important for prioritizing a limited number of low income areas for immediate service improvement within a certain budget. Figure 7 shows an example of a three-step area categorization including the sub-categorization of low income groups by religion. This example of sub-categorization is suitable in countries where certain religions have been marginalized in political decision-making regarding WS&S/OS services or where people of different religions use water in significantly different ways.

Low income group areas can be sub-categorized based on a single significant factor that influences the existing

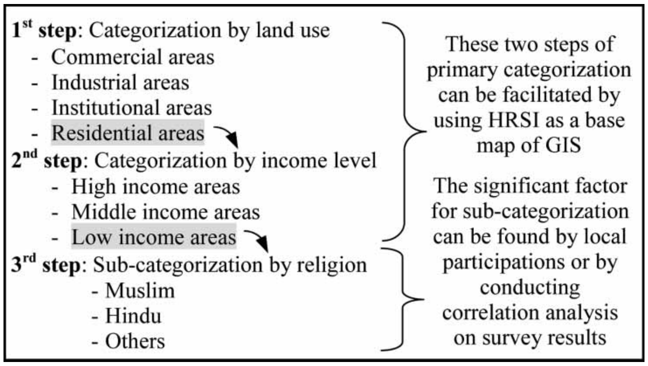


Figure 7 | Example of PGIS-based three-step area categorization.

service conditions and/or residents' preference for service improvement in the area. The significant factor may be religion (as illustrated in Figure 7), ethnicity, population density, elevation, area size or distance from the nearest water source. If coverage of existing distribution pipes and sewers has been clearly mapped with GIS, low income areas can also be sub-categorized geographically based on the existence of distribution pipes and sewers in their areas.

However, sub-categorization of low income areas during the preparation of sampling design is possible only when the significant factor can be identified and its variations within low income areas can be mapped (based on available documented data, existing database or local people's perception). This sub-categorizing process can be done more effectively by conducting a correlation analysis of household survey results. Using correlation analysis, we can identify the most significant factor that shows the highest correlation with the survey results.

Another important aspect in the design of a multistage sampling for a household survey in DCs is the method of representative sampling from each category or sub-category of the targeted areas. Since an extensive list of household addresses is usually non-existent or unobtainable in DCs, random sampling from each category or sub-category is usually quite difficult. However, various GIS functions (including those of free add-in GIS software such as Hawth's Tools for ArcGIS) and the HRSI base map can provide a great deal of help for random selection of sampling areas and households from each category and sub-category. For example, areas belonging to each category or sub-category can be geometrically divided with a mesh into area segments of similar size (practical size for field surveyors) by using GIS functions. Then, sampling areas can be selected randomly from the area segments of each category or sub-category with GIS functions. Households and residential buildings can also be sampled randomly from each sampling area, with the help of GIS, if existing residential buildings visible on the HRSI are digitized as points for random sampling.

Subsequent tasks of the primary sequence

As seen in Figure 1, after clarifying differences over various areas through a household survey using PGIS, an optimum geographical mix of different service levels should be prepared based on the results of the household survey. The prepared mix of WS&S/OS services should be presented on HRSI and discussed at a stakeholder meeting(s) for public consultation to enable further improvement of the mix.

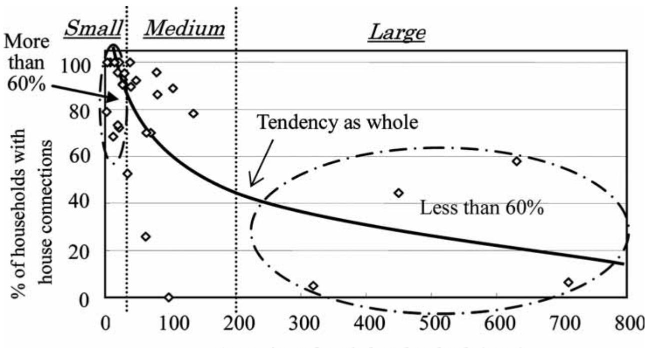
The household survey should include an investigation of current water consumption levels from different water sources in each area category and sub-category. Based on the results of this investigation, future per capita unit water consumption can be established for each area category and sub-category by taking various aspects (water demand management, correction of disparities, alternative water sources for non-drinking purposes, etc.) into consideration. The total future residential water consumption can be calculated with GIS functions by summing up the future water consumption in each residential area that can be expressed as a product of future unit consumption, future population density and area size in each area.

GIS can also help calculate initial costs, operational costs and expected operational revenues of the proposed optimal mix of different services at the estimated future water consumption levels for facility planning.

RESULTS OF A TRIAL USAGE IN PAKISTAN

The proposed methodology was partially used in a household survey conducted in Karachi, Pakistan, in 2006. The household survey is part of the development study funded by Japan International Cooperation Agency (JICA) for the augmentation of water supply and sewerage systems in Karachi. The subsequent results were obtained from that household survey (JICA 2008).

As a result of the correlation analysis conducted in the household survey, the area size of each of the low income areas (developed informally without legalized area planning and called *katchi abadis*) was determined to be the significant and most suitable factor for the sub-categorization of *katchi abadis* in Karachi. According to the analysis, the area size of each *katchi abadi* has significant influences on the availability of piped water supply services and needs for better services. A GIS function was used to calculate the area size of each *katchi abadi*. Figure 8 shows the relationship between the area size of each surveyed *katchi abadi* and the percentage of sampled households having house connections of piped water supply within the area. As shown in Figure 8, large *katchi abadis* tend to have lower percentages of households with house connections. This tendency is probably due to the difficulty of transporting water via pipes to inner residential blocks of large *katchi abadis* over long distances from adjacent higher income areas where most of the trunk distribution mains exist. Consequently, *katchi abadis* were sub-categorized by area size (with the identified boundary values of 30 and 200 acres) into three groups of small, medium and large *katchi abadis*, as seen in Figure 8.



Source: JICA 2008

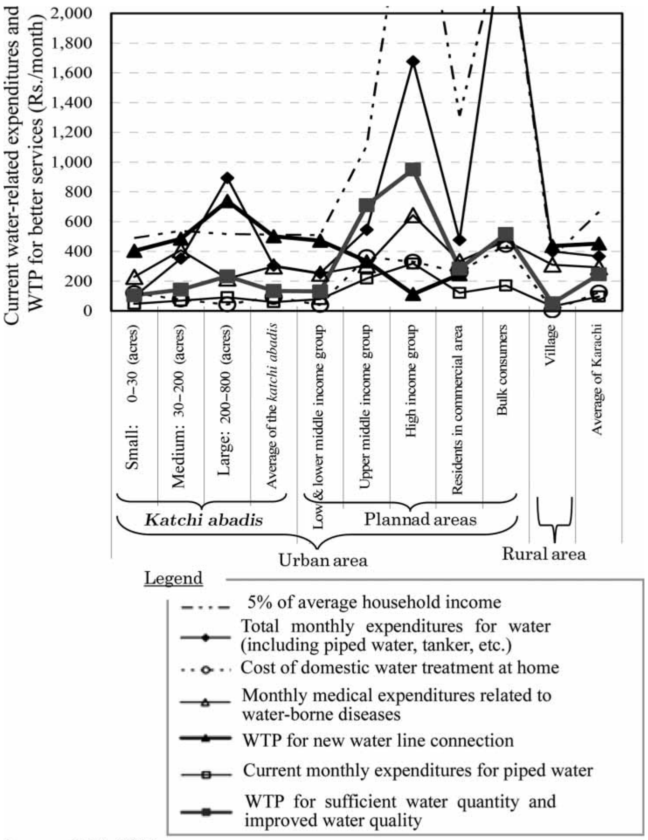
Figure 8 | Influence of Area Size on House Connections in Katchi Abadis.

Table 1 and Figure 9 show examples of the results from the household survey (including the current level of water consumption and WTP for improved water supply service) presented for each category and sub-category. In these examples, the initial area categorization by income level (based on local perceptions and visual interpretation of different household plot sizes seen on a base map of HRSI) was verified and modified by clarifying the range in average household income for each income group category. Initially, *katchi abadis* and villages were categorized as low

Table 1 | Example of different levels of unit water consumption

		Sub-category by area size (acre)	**From (>)**	**To (≤)**	**Average water consumption (L/capita/day)**
Urban	*Katchi abadis* (unplanned area, low and lower middle income)	Small	0	30	136
		Medium	30	200	95
		Large	200	800	59
		Average in *katchi abadis*			109
	Planned areas	Low and lower middle income areas			118
		Upper middle income areas			150
		High income areas			264
		Residents in commercial areas			164
		Residents in bulk supply areas			268
Rural	Villages (low and lower middle income)				77
Estimated average in Karachi					118

Source: JICA (2008).



Source: JICA 2008

Figure 9 | Analysis of the different levels of WTP for better services.

income areas while the most congested legitimate urban residential areas (excluding *katchi abadis*) were categorized as lower middle income areas. However, the results of the household survey showed that there is no significant difference between the pre-categorized low income areas and lower middle income areas. Therefore, Table 1 and Figure 9 shows revised income level categories reflecting this point.

As seen in Table 1 and Figure 9, it was found that large *katchi abadis* consuming the least amount of water (59 L/capita/day in total from various water sources) had the highest average WTP for new water line connection (more than Rs 700/month). Meanwhile high income areas and upper middle income areas had significantly higher WTP (more than Rs 900 and Rs 700/month, respectively) for sufficient water quantity and improved water quality. Therefore, it was planned to introduce continuous water supply with significantly higher water charges to some of these high and upper middle income areas first in order to increase annual revenue of the water utility while gradually expanding the existing water distribution network to *katchi abadis*, including large ones, in order to supply water to poor people in a sustainable way.

CONCLUSIONS

The adoption of DRA for large-scale urban WS&S/OS projects (covering various areas of different socio-economic groups) has been delayed. In order to expedite the adoption of DRA, this paper presented an innovative pro-poor methodology of DRA after reviewing the past developments of DRA, PGIS and HRSI. This new methodology integrates the three types of existing demand assessment technique (RP, PRA and CVM) for the implementation of DRA in large-scale urban WS&S/OS projects.

The methodology includes a new PGIS method that utilizes HRSI as a base map of GIS in the preparation of an effective sampling design for a household survey. Even the low income areas that have not been identified in past studies can be mapped through the proposed PGIS exercise by involving representatives from marginalized low income areas. The identification of low income areas is quite important to avoid the exclusion of low income groups from the subsequent facility planning.

The results of the PGIS-based household survey can be presented geographically for each primary category (by land use and income level) and sub-category (of low income areas). Therefore, the results can be easily reflected in the facility planning of WS&S/OS. The results of the PGIS-based household survey using HRSI can also be used for tariff setting and geographical subsidy targeting. The partial use of the new methodology in Karachi was successful to some extent, especially in terms of understanding the different conditions and needs of various geographically categorized socio-economic groups. It is expected that the planning of mixed WS&S/OS service levels can be effectively conducted by adopting the DRA methodology into full-scale practice.

The GIS-related costs of the proposed methodology (including the cost of HRSI) are not marginal. However, long-run utilization of the GIS and HRSI for the development and maintenance of GIS databases on existing water pipes, sewers and customers, etc., can be quite cost-effective for urban water utilities in DCs.

The methodology proposed in this paper is still in the development stage. Further practical applications of DRA in urban areas would be beneficial for the refinement and dissemination of this innovative methodology. This initial proposal will hopefully be a starting point for worldwide discussion on the possibilities of PGIS and HRSI in the realization of DRA for large-scale urban WS&S/OS projects in DCs.

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