

Research Paper

Locating water distribution reservoirs in rural Andean areas: a methodological approach

Nadya Lizeth Serrano Abarca and Welitom Ttatom Pereira da Silva

ABSTRACT

This study aimed to present a methodology for locating water distribution reservoirs in rural Andean areas (isolated areas, low-income population, mountainous region). The research methodology consisted of the following steps: (1) description of the problem; (2) development of the DR location protocol; (3) obtaining an algorithm; (4) calibration and adjustment; and (5) application. The obtained algorithm was based on the classification and overlapping operations of five-parameter maps (pressure limits – pressure in the water supply system from 5 to 40 mH₂O; supply by gravity – guarantee of gravity as energy for water movement; accessibility – use of unprotected areas or with restricted occupation; stability, greater distance from geological fault; and, proximity to population concentration, shorter distance between population centres). The overlapping of these parameters enabled us to identify a region of candidate points and select the best location point for the reservoir. The algorithm was applied to a real case indicating satisfactory results. A methodology for locating water distribution reservoirs in rural areas that have important economic constraints, difficult access (mountainous region) and high geospatial dispersion was found. Improvements in methodological steps can still be considered, for example, forecasting the use of pressure control devices in the water supply system.

Key words | adequate location, rural water, water reservoir, water supply systems

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INTRODUCTION

The best designs of Rural Water Supply Systems (RWSS) can be obtained from iterative methodologies that do not use conventional solutions (Goulter 1987; Alperovits & Shamir 1997). One way would be to use data entry (physical attributes, diameters, lengths, characteristics and location of distribution reservoirs, pumps, flow demands and others) in software based on mathematical programming techniques or artificial intelligence (Mays 2002). Therefore, the location of the Distribution Reservoir (DR) is presented as input data to obtain better designs of water supply systems. Obtaining this location proves to be very challenging, especially in rural areas that have important economic constraints (with no capacity for public indebtedness, low-income population), difficult access (high mountainous areas) and high

geospatial dispersion, which is a typical case of rural Andean areas.

DRs in rural Andean areas are directly gravity-fed, taking advantage of potential energy, reducing implementation and operating costs. Most of these rural areas do not have any technical information regarding the implementation of RWSS designs and, because of this, obtaining geospatial information for locating DRs is a very important tool within the territorial administration of rural Andean areas.

Despite the importance of carrying out studies on locating DRs, there has been no progress in methodological proposals for rural water supply systems (Huang *et al.* 2011). Currently, research in the RWSS area focuses on management and sustainability, showing little progress in design

techniques. As an example of research focusing on management and sustainability, *Jovanović et al. (2017)* studied water quality in rural areas of Serbia and their results indicated the need for rehabilitation. *Kativhu et al. (2017)* identified the fusion of social, technical, financial, environmental and institutional factors as influencing sustainability of RWSS in Zimbabwe. *Barde (2017)* analysed the reasons for expanding RWSS in Brazil. The main reasons are related to greater responsibility for water, media presence, competition in the electoral period and political and economic growth in the country. In another study, *Chi et al. (2018)* assessed the Mekong Delta RWSS status and measures for developing it. The uncontrolled consumption of quality of water and numerous structural problems in the RWSS facilities were found (*Chi et al. 2018*). A framework for assessing and comparing the sustainability of RWSS considering technical, financial, institutional, social and environmental dimensions was developed by *Wijesinghe et al. (2019)*. Moreover, according to *Wijesinghe et al. (2019)*, policymakers should make it mandatory to consider these dimensions before approving funding for the rehabilitation or increase of RWSS.

As an example of research which has a technical focus, *Silva et al. (2016)* developed and applied a multi-objective optimization model (based on Multi-objective Integer Non-linear Programming) for RWSS in the city of Cuiabá, State of Mato Grosso, Brazil. The findings report that minor structural changes and proper operation can promote pressure equity in the water supply system (*Silva et al. 2016*). Similarly, *Kurian et al. (2018)* developed an optimization model (based on Linear Programming) of an RWSS with a main reservoir, multiple secondary reservoirs in small villages, mains and valves. *Kamanga et al. (2018)* evaluated using the rope pump for water supply in rural areas of Malawi. Their results indicated failure in 27% of the pumps installed. The main reasons were the rope breaking and the need for operation and maintenance training. *Foris et al. (2018)* studied an alternative (rainwater) for water supply in isolated rural units in mountainous regions. The alternative proved to be important for water supply in the winter period when there is little water availability in mountain regions.

In this scenario, spatial analysis digital technologies (GIS-Geographic Information Systems) can be considered as suitable tools and of interest in terms of resolving socio-spatial problems (*Buzai & Baxendale 2010; Buzai 2014*).

Thus, this research aims to develop and apply a protocol, based on the interaction between GIS and water supply hydraulics, to locate DRs in rural Andean areas. The protocol will contribute to improving the quality of RWSS and water availability for rural Andean areas.

STUDY AREA

The study was carried out in the rural area of the municipality of Sigchos, belonging to the inter-Andean Cotopaxi province Ecuador.

The study area was identified as a priority intervention region, due to the high percentage of poverty and high levels of inequality between the poor and rich (*SENPLADES 2012*). Other important features of the study area include the following:

- The water is collected from a hillside water source (point and downstream outcropping) originating from melting mountainous regions and perennial streams;
- Population dispersion, large distance between residences (*MSP 2009*);
- Problem of accessing rural Andean settlements (steep slopes greater than 70%, high mountainous areas with difficult access);
- Impairing the drinking water supply to the population, which worsens existing health problems (*MSP 2009*);
- Water for human consumption is managed through local organisations at the community level, legally recognized as Water Management Boards (*GAD Municipal de Sigchos 2015*);
- Developing and implementing water supply system designs (catchment, adduction, reservation and distribution) empirically due to the lack of technical data, human and financial resources. This, of course, results in a limitation of access to water and obliges the population to assume health risk behaviour, such as using inadequate water sources for consumption.

For this study, the supply area was defined by the catchment point administered by the Guasumbini Bajo Community Water Board, with two contiguous drainage units or micro-basins located on each side of the catchment point (watershed). This imaginary line separating the waters

marks the boundary between two residential agglomerations in the opposite direction, generating two polygons corresponding to the experimental area (5.01 km²) and the application area (7.04 km²). These areas have Zapotillo geological formations, Naranjal volcanic sediments and Quilotoa Volcano-sediments presenting geological faults.

METHODOLOGY

The proposed methodology comprised of the following steps: (1) problem description; (2) development of the DR location protocol; (3) obtaining an algorithm; (4) calibration and adjustment; and (5) application.

In the problem description step, information about the experimental area, the difficulties faced by the population and local constraints were collected. Moreover, hypotheses, elements and a theoretical basis were obtained (SA 1992; ABNT 1994; Pittman 1997; Tsutiya 2006).

To develop the DR location protocol, the technical literature was consulted, and later activities inherent to the gravity water supply design were suggested (Pittman 1997; Tsutiya 2006). Inherent activities included ensuring availability of water (maximum and minimum pressures), accessibility (operation and maintenance), stability (safety) and economic limitation.

In the obtaining of an algorithm step, we chose the logical organisation of the activities (step-by-step) to solve the problem (Taha 2008). Structured programming and pseudocode were used for programming and representing the algorithm, respectively. To obtain the algorithm, a precise understanding (data, equations and geoproceses) of the activities was carried out: gravity-fed water supply system design; guarantee of water availability; accessibility, stability; and economic limitation. Then, the logical ordering (step-by-step) of this understanding and its representation were carried out. The example of this step is defined as follows:

$$D = \{D1, D2, \dots, Dn\}$$

$$E = \{f_1, f_2, \dots, f_n\}$$

$$G = \{G1, G2, \dots, Gn\}$$

$$D1 \rightarrow G1$$

$$D2 \rightarrow f_1$$

$$f_1 \wedge G1 \rightarrow G2$$

$$D3 \rightarrow f_2$$

$$Dn \wedge f_2 \rightarrow f_3$$

$$G2 \wedge f_3 \rightarrow G3$$

$$G3 \rightarrow Gn$$

where *D* is the data set; *E* is the equations set; *G* is the geoproceses set; ‘→’ is the logical concept ‘if ... then’; ‘∧’ is the logical concept ‘and’. This logic sentence set can also be represented as a pseudocode (algorithm) as follows:

1. $G1_{OUT} = G1(D1)$, where $G1_{OUT}$ is the output $G1$.
2. $G2_{OUT} = G2(f_1(D2), G1_{OUT})$, where $G2_{OUT}$ is the output $G2$.
3. $G3_{OUT} = G3(G2_{OUT}, f_3(Dn, f_2(D3)))$, where $G3_{OUT}$ is the output $G3$.
4. $Gn_{OUT} = Gn(G3_{OUT})$, where Gn_{OUT} is the output Gn .

For the calibration and adjustment step, qualitative tests (compliance/non-compliance, water availability criteria, accessibility and stability) were performed. If the qualitative test indicates they were not complied with (water availability, accessibility, stability), step-by-step adjustments would be made. The qualitative test consisted of a questionnaire with four criteria, the first two related to water availability, and the third and fourth related to accessibility and stability, respectively. The questionnaire with answers from a case study is presented below:

- Criterion 1: Does the location of the DR allow households to receive gravity water?
 Yes No
- Criterion 2: Does the location of the DR allow the intake to feed the DR by gravity?
 Yes No
- Criterion 3: Is the location of the DR outside protected areas or with restricted occupation?
 Yes No
- Criterion 4: Is the location of the DR outside geological faults?
 Yes No

In this example, criteria 1, 2 and 3 are met and criterion 4 is not met, therefore there is a need for calibration and adjustments in the step-by-step process in order to meet

criterion 4. At this step, data from the experimental area were used.

For the application step, the location protocol and algorithm in the application area were used, and the results were also analysed.

RESULTS

In order to describe the next problem, some characteristics of the experimental area are presented. In Figure 1, a representation of the experimental area, including the water source (catchment), typical residence ($i = 1, 2, \dots, n$), steep slopes greater than 70% (high mountainous areas with difficult access) and DR location alternatives ($j = 1, 2, \dots, m$) is presented.

The experimental area has 12 residences ($i = 1, 2, \dots, 12$) geographically dispersed (horizontally and vertically). The residences are currently supplied from direct catchments (using buckets or similar recipients) and the population is forced to overcome difficulties of obtaining water, requiring

physical effort, long distances and high altitudes. To help solve the problem, the hypothesis of this study is that an RWSS (capture, adduction, reserve and distribution) based on gravity as energy for water movement is viable. This hypothesis is compatible with the criteria of water availability, accessibility and stability.

This considers the economic limitation as the operation dispenses energy consumption (there is no need to use pumps or electrical equipment) and it can be summarized in open/close manual valves.

Developing the adduction and distribution pipes depends on the reservation unit. Therefore, the first need is to develop the reservation project (definition of volume, physical structure and location). To define the volume and the physical structure of the reservation unit, there are various studies presenting details and calculations for gait and procedures (Wagner & Lanoix 1959; Pittman 1997; Mays 2002; Tsutiya 2006). However, to define the DR location, the literature presents only guidelines (criteria) without details, and calculations for gait or procedures, making the definition of DR location an empirical task. Therefore, the problem is to determine the best location for DR installation considering the restriction of operating the gravity-fed RWSS. The DR located at high elevation (positions 1 and 2, according to Figure 1) can generate low pressures in the adductor system and high pressures in the distribution system, increasing the loss index. Conversely, the low elevation DR (positions 3 and m , according to Figure 1) may disrespect the gravity-fed supply restriction (supply failure, water does not reach homes), and generate high pressures in the adductor system, intermittence in the distribution system, and others. For example, the DR location alternative $j = 3$ resulted in the residence $i = 1$ under high pressure and the residence $i = n$ affected by water outage, as shown in Figure 1.

As the basis of the treatment of the problem, an equation of the energy is applied to real fluids as presented below:

$$p_1/\gamma + v_1^2/2g + z_1 = p_2/\gamma + v_2^2/2g + z_2 + hf$$

where p_1/γ and p_2/γ are pressure loads at points 1 and 2; $v_1^2/2g$ and $v_2^2/2g$ are velocity heads at points 1 and 2; z_1 and z_2 are the geometric loads at points 1 and 2; and hf is

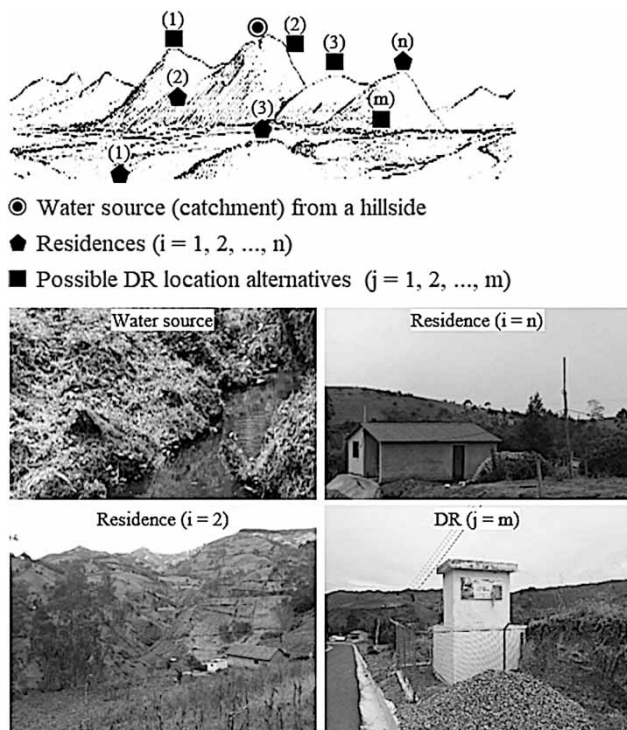


Figure 1 | Experimental area.

the load loss that occurs between points 1 and 2. The values of p_1/γ and p_2/γ were obtained from using the energy equation, $v_1^2/2g$ and $v_2^2/2g$ were obtained from estimates of population consumption and pipe diameter, z_1 and z_2 were obtained from the Digital Terrain Model (DTM).

This equation estimates pressures in hydraulic systems and responds to the issue of meeting the pressure limits in the residences from certain hydraulic characteristics of the system (pressure, flow, diameter, others). The Fair-Whipple-Hsiao (FWH) equation was used to calculate the load loss for diameters less than 100 mm and plastic pipes, common in RWSS (Porto 2006; Silva *et al.* 2016). The FWH equation is shown below:

$$hf = 0.0008695Q^{1.75}D^{-4.75}L$$

where Q is the flow conducted in the pipe ($\text{m}^3 \cdot \text{s}^{-1}$); D is the diameter of the pipe (m); L is the length of the pipe (m).

A set of steps and activities is presented based on map overlapping as the DR location protocol (with previous track vector files) of five evaluation parameters, defined on a work scale of 1:5,000, as follows:

- Step 1: pressure limits, PL (see Table 1, set of steps 1.1–1.3);
- Step 2: gravity supply, GS (see Table 1, set of steps 2.1 and 2.2);
- Step 3: accessibility, AC (see Table 1, set of steps 3.1 and 3.2);
- Step 4: stability, S (see Table 1, set of steps 4.1 and 4.2);
- Step 5: proximity to the largest population density, PPD (see Table 1, set of steps 5.1–5.5).

Selecting the appropriate DR point consists of the pixel (size 3×3 m) of the numerical value closest to 1, resulting in overlapping maps.

As a result of obtaining the algorithm step, we have the pseudocode (algorithm) shown below:

1. $FR1 = f_{FR1}(DMT, x1, P_{min})$.
2. $FR2 = f_{FR2}(DMT, x2, P_{max})$.
3. If $(FR1 \cap FR2) = \neg \text{null}$, then $FR2 = (FR1 \cap FR2)$, otherwise $FR2 = FR1$, where ‘ \cap ’ stands for the concept ‘intersection’, ‘ \neg ’ for the logical concept ‘not’ and ‘null’ stands for the concept ‘empty’.

4. $FR3 = f_{FR3}(FR2, x3)$.
5. $FR4_{OUT} = FR4(FR3, x4, x5)$, where $FR4_{OUT}$ is the output of FR4.
6. $FR5_{OUT} = FR5(FR4_{OUT}, x6)$, where $FR5_{OUT}$ is the output of FR5.
7. $FR6_{OUT} = FR6(FR5_{OUT}, x3, x7)$, where $FR6_{OUT}$ is the output of FR6.
8. $DRL = \max(FR6_{OUT})$, where DRL is the DR location and $\max(FR6_{OUT})$ is the largest proximity between FR6 and the population density.

The algorithm, after input, performs sequential activities, decision activities and presents the DR location. Called rural-DRL, the algorithm was based on the LP, GS, AC, S and PPD parameters (Table 1) and was implemented in geoprocessing software. If the pressure limits (maximum and minimum) are not met, then the minimum pressure limit must be prioritized. The possibility of using pressure reducing equipment (for example, pressure reducing valve, pressure drop chamber, intermediate reservoir, other) justifies this option. Inserting the pressure reducing equipment can guarantee compliance with maximum pressure values and, consequently, meet the objective of the study.

In order to analyse and identify the need for calibration and adjustment, characteristics and the evolution of the feasible region (FR) depends on processing the rural-DRL algorithm, when applied in the experimental area, according to Figure 2. The results of estimated pressures in the residences ($i = 1, 2, \dots, 12$) ranged between 7 and 86 mH_2O , the value average is 46 mH_2O .

The analysis of Figure 2 suggests the suitability of the rural-DRL algorithm to its objective as it resulted in the best location of the DR. The location chosen to install the DR ensures water availability for the residences (pressures regarding the minimum limit, minimum pressure 6.6 mH_2O), allowing its operation by gravity (adductor and supply to residences), greater accessibility, stability and proximity of population density. Failure to meet maximum pressure in some residences (maximum pressure 86 mH_2O) was observed, indicating the absence of a feasible region to meet the maximum and minimum pressures simultaneously. Therefore, for the experimental area, pressure reducing equipment needs to be installed in order to meet

Table 1 | Description of the parameters: pressure limit (PL); gravity supply (GS); accessibility (AC); stability (S); and proximity to the largest population density (PPD)

| Step | Description | Activity | Reference |
|------|--|--|------------------------------|
| 1.1 | Location of residences with the highest and lowest quotas from the digital terrain model (DTM) | <ol style="list-style-type: none"> 1. Locate the residence of the highest elevation and obtain the quota (x_1) 2. Locate the residence of the lowest quota and obtain the quota (x_2) | Tsutiya (2006), Porto (2006) |
| 1.2 | Definition of feasible region considering the minimum dynamic pressure criterion | <ol style="list-style-type: none"> 1. Define the minimum dynamic pressure (in this case, the $P_{\min} = 5 \text{ mH}_2\text{O}$) 2. Define feasible region (FR1) according to the equation: $f_{\text{FR1}} = \begin{cases} 1, & \text{if } z \geq x_1 + P_{\min} \text{ hf}_R \\ 0, & \text{otherwise} \end{cases}$ 3. Digital classification of DTM according to FR1 (1 for the feasible region; 0 for otherwise) | SA (1992) |
| 1.3 | Definition of feasible region considering the maximum dynamic pressure criterion | <ol style="list-style-type: none"> 1. Define maximum static pressure (in this case, the $P_{\max} = 40 \text{ mH}_2\text{O}$) 2. Define feasible region (FR2) according to the equation: $f_{\text{FR2}} = \begin{cases} 1, & \text{if } P_{\max} \geq z_R - x_1 \\ 0, & \text{otherwise} \end{cases}$ 3. Digital classification of DTM according to FR2 (1 for feasible region; 0 for otherwise) | SA (1992) |
| 2.1 | Location of the catchment point based on DTM information | <ol style="list-style-type: none"> 1. Locate catchment point and obtain quota (x_3) | Jiménez <i>et al.</i> (2016) |
| 2.2 | Definition of feasible region considering the gravity-fed operation | <ol style="list-style-type: none"> 1. Define feasible region (FR3) according to the equations: $a = \begin{cases} 1, & \text{if } x_3 \geq z_R + \text{hf}_A \\ 0, & \text{otherwise} \end{cases}$ $b = \begin{cases} 1, & \text{if } z_R \geq x_1 + \text{hf}_{R,x_1} \\ 0, & \text{otherwise} \end{cases}$ $f_{\text{FR3}} = \begin{cases} 1, & \text{if } (a = 1) \text{ and } (b = 1) \\ 0, & \text{otherwise} \end{cases}$ 2. Digital classification of the DTM according to the FR3 (1 for the feasible region; 0 for otherwise) | Jiménez <i>et al.</i> (2016) |
| 3.1 | Definition of coverage and land use based on the DTM information | <ol style="list-style-type: none"> 1. Survey of plans, reports, protected areas, occupation restriction and others (x_4) 2. Digital classification of DTM for different coverages, land use and occupation (1 for very desirable coverage, 2 for moderately desirable coverage, ..., x for undesirable coverage), see Figure 2(d) | Tsutiya (2006) |
| 3.2 | Adoption of feasibility for location, operation and maintenance of DR (right of way near tracks, roads and existing roads) | <ol style="list-style-type: none"> 1. Locate tracks, roads and roadways (x_5) 2. Define right of way (FR4) as 500 m from the right and left sides of the tracks ($y = 3$), roads ($y = 2$) and roadways ($y = 1$) 3. Restriction of DR location in non-suitable coverage and land use areas (marsh, mining, etc.) 4. Digital classification of the DTM according to FR4 with normalization of values (1/y: degree of easiness of accessibility and coverage and land use; 0 for restriction of location: no accessibility), see Figure 2(a) | Tsutiya (2006) |

(continued)

Table 1 | continued

| Step | Description | Activity | Reference |
|------|---|--|--|
| 4.1 | Physical delimitation of susceptibility to mass displacements | 1. Construction of categories weighted according to the eligibility of lower threat sectors, geological fault location (x_6) 2. Digital classification of DMT according to categories: low (4); mean (3); moderate (2); and high (1) | Tsutiya (2006) |
| 4.2 | For geological faults that predispose instability probabilities | 1. As a measure of damage reduction (safety), the locations with greater distances of geological faults and greater stability to mass displacements (FR5) are adopted. The normalization of values is considered, where 1 is desirable (maximum value), 0 for otherwise, see Figure 2(b) | SNGR (2015) |
| 5.1 | Location of the catchment point from the digital terrain model (DTM) | 1. Locate catchment point and obtain coordinates (x_3) | Tsutiya (2006), Jiménez <i>et al.</i> (2016) |
| 5.2 | Location of the residence farthest from the catchment point from the digital terrain model (DTM) | 1. Locate farthest residence from catchment point and obtain coordinates (x_7) | Tsutiya (2006), Jiménez <i>et al.</i> (2016) |
| 5.3 | Creation of a restriction polygon of the optimal positioning (related to the length and cost of the adductor) | 1. Create polygon from the coordinates (x_3) and (x_7), common quadrants between the coordinates | Tsutiya (2006), Jiménez <i>et al.</i> (2016) |
| 5.4 | Rasterized with value encoding 1 for pixels that are within tolerance limits | 1. Digital classification of DTM (1 for feasible region, pixels within tolerance limit, 0 for otherwise), obtaining FR6 | Tsutiya (2006), Jiménez <i>et al.</i> (2016) |
| 5.5 | Definition of population density (residence/a) | 1. Use of core density (Kernel) for the expression of density population regions 2. As a measure of operational ease, the lowest distance location of the zone with the highest population density, called DR location (DRL), is adopted. We consider normalization $1/x$ of the distances, where x is the distance from the centroid to the pixel, see Figure 2(c) | Silverman (1986) |

z is the terrain quota in the experimental area; z_R is the DR quota at the adopted location; hf_R is the pressure drop in the DR outflow pipe to the residence (FWH equation, L_R obtained by the linear distance between DR and the residence, $D_R = 50$ mm, High-density polyethylene (HDP) pipe material, $Q_R = p \cdot pa$ where p is the number of inhabitants of the residence and pa is the per capita water consumption); hf_A is the pressure drop in the adductor, catchment until the DR (FWH equation, L_A obtained by the linear distance between the catchment and the DR, $D_A = 50$ mm, material of the PEAD pipe, $Q_A = \sum Q_R$); $hf_{R,x1}$ is the pressure drop in the DR output pipe to the residence x_1 ; a is the binary variable that represents the feasibility of locating the DR according to the catchment point; b is the binary variable that represents the feasibility of locating the DR according to the residence of the highest quota.

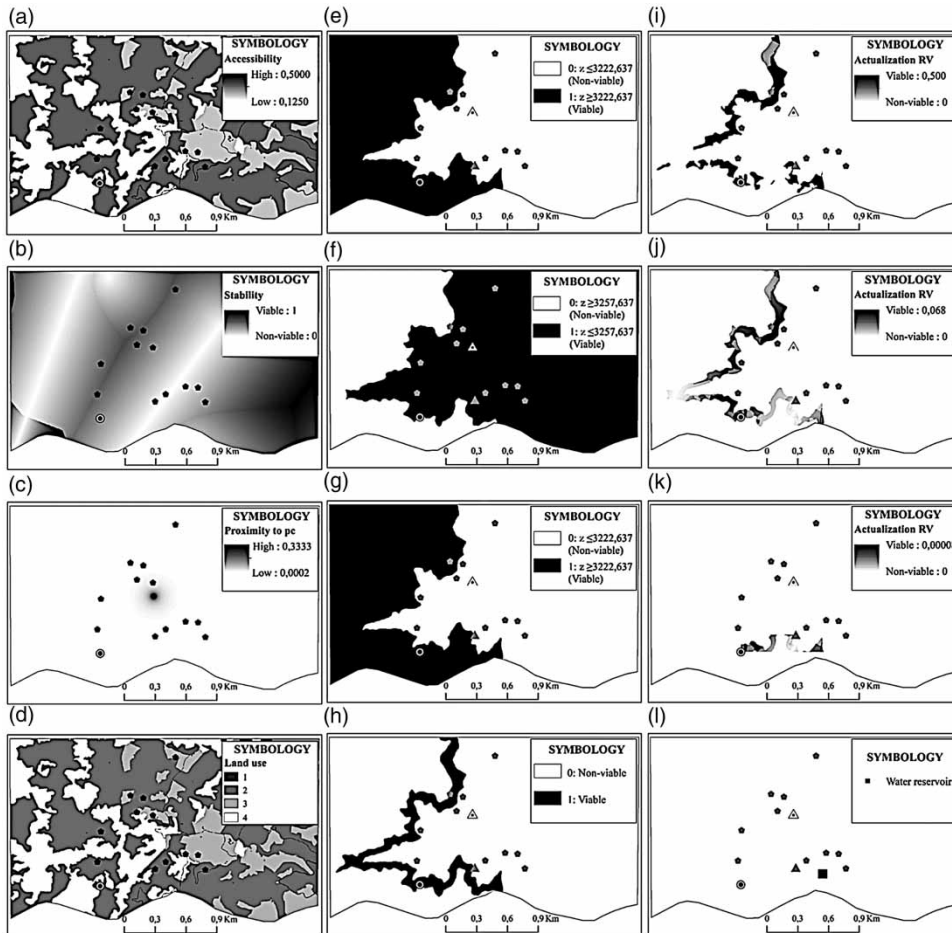
the maximum pressure (40 mH₂O), for example, pressure reducing valve, pressure drop chamber, load loss generator part, others).

No difficulties or failures (high computational time for processing, inability to supply water, incompatibility between parameters) were observed in the results presented by the rural-DRL algorithm, therefore the calibration and adjustment activities were considered unnecessary. The result of the qualitative test is presented below:

- Criterion 1: Does the location of the DR allow households to receive gravity water?
 Yes No

- Criterion 2: Does the location of the DR allow the intake to feed the DR by gravity?
 Yes No
- Criterion 3: Is the location of the DR outside protected areas or with restricted occupation?
 Yes No
- Criterion 4: Is the location of the DR outside geological faults?
 Yes No

The characteristics of the application area and results of the application step are shown in Figure 3. Values of pressures in the application area residences ($i = 1, 2, \dots, 47$)



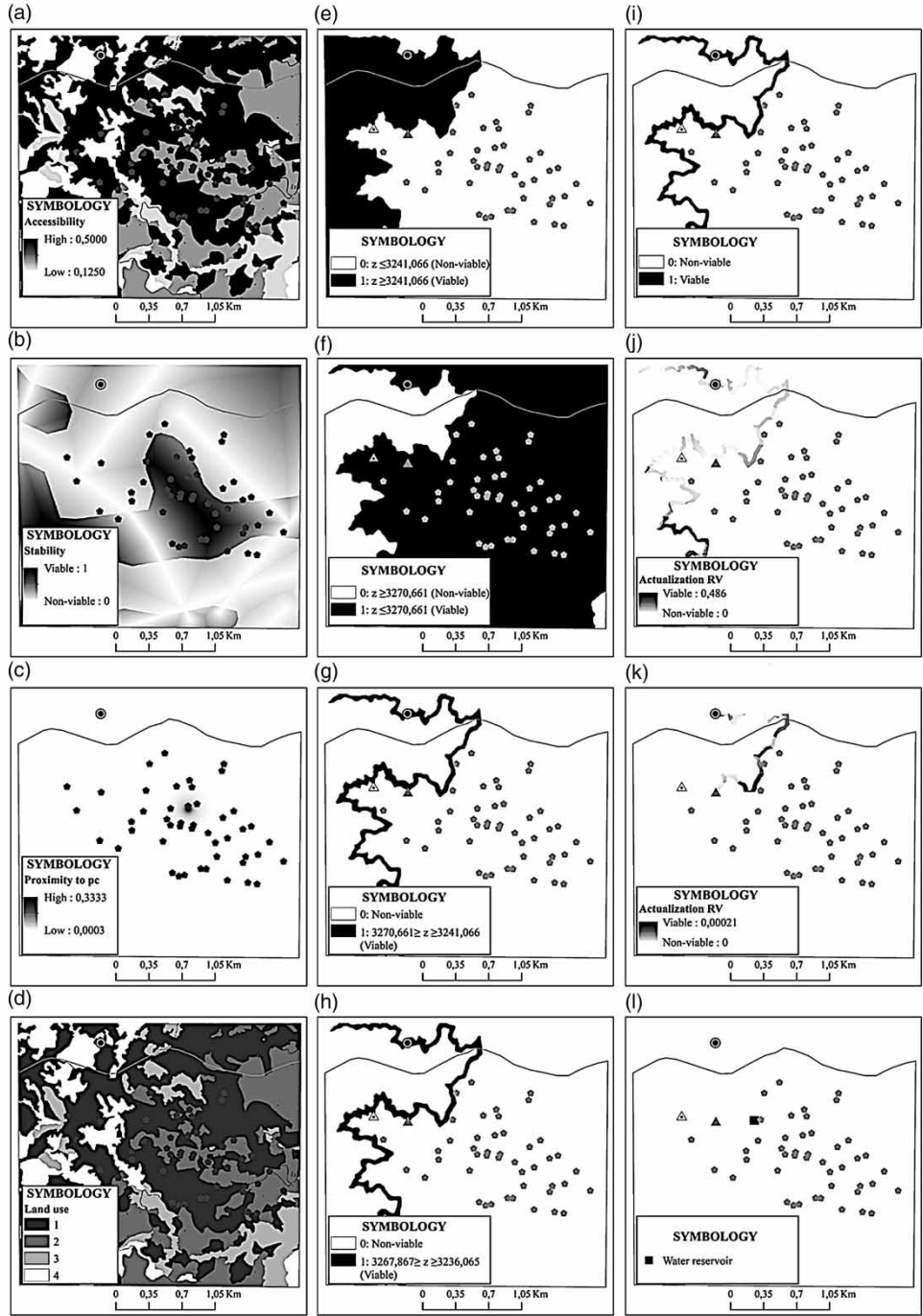
(a) accessibility, related to the proximity of roads and land use; (b) stability, related to the removal of geological faults; (c) proximity to the largest population density; (d) land use and cover, 1 is the marsh, 2 is the pasture, 3 is the crop, and 4 is the forest; (e) until (l) is the evolution of the feasible region
 ● Catchment point, ● Residences in the experimental area
 □ Experimental area (5.04 km²), ▲ Highest residence, △ Lowest residence

Figure 2 | Characteristics of the experimental area and step-by-step follow-up of rural-DRL algorithm.

ranged between 11 and 378 mH₂O, the average is 202 mH₂O. The results of the pressures show difficulties and failures in the rural-DRL algorithm as in order to reach the minimum values of pressures in the residences there is a need for elevation in the residences in lower regions.

Obviously, there is a need for pressure reducing equipment, for example, pressure reducing valve, pressure drop chamber, load loss generator part, others. Moreover, selecting and locating it well in the rural water supply system merits studies. This may make implementing the results impossible for the application area (high pressures require

special piping and possibly high costs including pressure reducing equipment). This is a clear limitation of the rural-DRL algorithm and is not recommended for areas with differences in topographic quotas over 100 m. An alternative to eliminating this limitation would be the successive application of the rural-DRL algorithm to variation intervals of topographic quotas of 40 m (from the catchment up to 40 m below the rural-DRL algorithm applied; the DR is located and this becomes the new catchment for meeting 40 m below; then the process is repeated until the lowest topographic quota residence is reached).



(a) accessibility, related to the proximity of roads and land use; (b) stability, related to distancing of geological faults; (c) proximity to the largest population density; (d) land use and cover, 1 is the marsh, 2 is pasture, 3 is the crop, 4 is the forest; (e) until (l) is the evolution of the feasible region
 ● Catchment point, ● Residences in the application area
 □ Application area (7.01 km²), ▲ Highest residence, △ Lowest residence

Figure 3 | Characteristics of the application area and step-by-step follow-up of the rural-DRL algorithm.

CONCLUSIONS

A protocol, based on the interaction between GIS and water supply hydraulics, to locate distribution reservoir for rural Andean areas was developed and applied. The protocol which was developed is an effective tool (rural-DRL algorithm) to identify suitable reservoir location sites for the water supply system in rural Andean areas. Considering the current form of reservoir location (empirical method), this method of reservoir location is expected to reduce investment and operating costs in planning rural water supply systems. Selecting the parameters of analysis considered the technical characterizations commonly used to develop gravity-fed water supply projects.

It is highly recommended that research and governance institutions, especially those aimed at rural water supply, continue the study. The focus should be on overcoming the limitation (not meeting maximum pressures) of the methodological proposal.

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