NGUYEN DUC VIET

RESEARCH ON BUILDING SUPPORT METHODS FOR DECENTRALIZATION OF MANAGEMENT AND EXPLOITATION OF IRRIGATION WORKS FOR WATER USER ORGANIZATIONS IN QUAN LO - PHUNG HIEP AREA

Speciality: Water Resources Engineering
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SUMMARY OF DOCTORAL THESIS

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At…. ….., Date …./…. / 2017

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INTRODUCTION

1. The urgency of the thesis

Quan Lo-Phung Hiep is one of the five areas which have largest irrigation systems (the same name) in the Mekong Delta, serving the irrigated area for about 280,000 ha and 430,000 water users. The water resource is from tributaries of the lower section of Mekong River. The entire system has more than 100 km of main canals, 426 km of level 1, 28 salinity-retaining sewers and thousands of pumping stations.

Currently, Quan Lo-Phung Hiep (QL-PH) irrigation system only has over 350 workers, who are directly managing the key irrigation works, with averagely one irrigation staff manages about 65 km of canal. In the irrigation system the main canals and the channels of level 1 and level 2 are managed by one worker with 22 km and 36 km, respectively; In addition, the irrigation works are usually located in large areas, spreading from one province to another, one district to other districts. Due to the insufficiency in human resources, many irrigation works in the QL-PH in particular are not managed by the real managers. As a result, many degraded irrigation works with the waste and the serious water loss in the context of climate change and sea level rise are strongly impacting to QL-PH region.

In order to improve the effectiveness of exploiting existing irrigation works, besides the construction solutions, a non-construction solution are proposed by the International Irrigation Experts, which is necessary to accelerate the process of decentralization of management and exploitation for Water Users Organizations (WUOs).

At the QL-PH area, the proposal for the decentralization of management and exploitation of irrigation works for WUOs is applied mainly in accordance with Circular No. 65/2009/TT-BNNPTNT (TT65) in terms of area (km², ha), construction type (canals, sewers, pumping stations, etc.) or level of construction (level 1,2,3 or on-farm). However, the reality has revealed many difficulties and
obstacles in the implementation of the Irrigation Management Transfer (IMT) according to the decentralization proposal such as: (i) Not suitable with the characteristics of irrigation works; (ii) Not taking into account market factors; (iii) Not promoting irrigation socialization; (iv) Not really effective and sustainable. The reason for these is that the decentralization criteria are quite rigid and lack flexibility, so it is very difficult to apply to the irrigation systems that lack management and exploitation organizations as QL-PH.

Therefore, it is necessary to study and develop a method to support the decentralization of management and exploitation of irrigation works for WUOs in QL-PH irrigation system.

With a different approach to the existing researches, this thesis proposes 01 decentralization criterion which is the perception of hydraulic works of water users as the foundation, combined with the indexes and algorithms (statistics, probability, optimal, etc.) to build and complete a method to support the decentralization of management and exploitation of irrigation works for WUOs. Case study is Quan Lo-Phung Hiep irrigation system.

2. **Purpose of the thesis**

The research supposes methods to support the decentralization of irrigation management and exploitation of irrigation works for WUOs in the inter-province irrigation system of QL-PH.

3. **The subject, scope and contents of the thesis**

3.1. **Research subjects:**

- Decentralization of management and exploitation of irrigation works.

- The correlation between the efficiency of the irrigation system and the perception of hydraulic works of water user at the time of this research and after decentralization (*according to assumed scenario*).

- Hydraulic works and entities directly managing and exploiting such works; the focus is on water users.
3.2. Research scope:

Two-thirds of the major tasks of decentralization of management and exploitation of irrigation works for WUOs under the TT65, which are: (i) Water Management; (ii) Construction Management.

3.3. Research content:

- Build, test the objectivity and reliability of the two sets of indicators: (i) Effectiveness of the exploiting irrigation works; (ii) Awareness of hydraulic works of the water users.

- Application of method to support decentralization in QL-PH, based on the calculation, introducing 03 optimal scenarios with the highest value of irrigation system exploitation efficiency.

- Analyzing and selecting 01 scenario suitable with production reality as the basis to developing the IMT promotion roadmap under the proposed decentralization.

4. The used research methods

- The hypothetical method: to solve the research problem.

- The method of investigation: collecting data, information.

- The mathematical method: to discover the correlation.

- The modeling approach: to simplify the complexity of the study.

- The prediction method: to predict the cognitive tendency.

- The expert method: identifying, helping guide optimal solution.

5. New contribution of the thesis

- Building a new method to support the decentralization of management and exploitation of irrigation works for WUOs; Application of the above method to QL-PH irrigation system has shown a correlation between the efficiency of exploitation of irrigation works and the perception of hydraulic works of water users through Pearson coefficient (r) from 0.65-0.70.

- Proposing 01 set of indicators evaluating awareness of irrigation works of water users; Through the reliability, objectivity and rationality check, 10/14 indicators from the set of indicators evaluating
awareness of hydraulic works of water users are appropriate to the agricultural conditions in QL-PH irrigation system.

6. **Scientific and practical significance**

6.1. **Scientific significance:**
- The relationship between the effectiveness of irrigation works and the perception of water users has been shown through Pearson coefficient (r) ranging from 0.65-0.7, the correlation result have been expressed by specific mathematical equations with high reliability.
- Has been developed 02 the sets of indicators regarding the effectiveness of exploiting irrigation works (07 indicators) and the set perception of hydraulic works of water users (14 indicators).
- Has been developed a method to support the decentralization of management and exploitation of irrigation works (including methodology, approach method and specific method) for grassroots irrigation organizations based on indicator sets and multi-objective optimization algorithm (multi-variable).

6.2. **Practical significance:**
- Contributing to solving problems and obstacles in the process of assigning tasks of management and exploitation of the irrigation works in QL-PH irrigation system.
- Contributing to the development of IMT roadmap for WUOs in the coming years based on a matrix supporting the decentralization of management and exploitation of irrigation works.

**CHAPTER 1: OVERVIEW OF DECENTRALIZATION OF MANAGEMENT AND EXPLOITATION OF IRRIGATION WORKS**

1.1. **Overview of irrigation decentralization history in the world**

The process of reforming irrigation management from 1980 up to now shows that decentralization of management and exploitation of irrigation works has a close relationship with IMT. The highest
development of a decentralization scheme is the feasible application of the such decentralization proposals to IMT implementation, which is also the basis for reforming the model of managing and exploiting irrigation works (Figure 1.4).

Figure 1.4. The process of reforming of irrigation management in irrigated agriculture from 1980 to present.

The motivation for countries to implement IMT under the decentralized management of irrigation works is to save public investment (in most countries) and ensure sustainable O&M (Mexico, Chile) or to improve the efficiency of irrigation (Andhra Pradesh, India). The motivation of WUs is to gain control in irrigation water management (Columbia, USA and Australia) and to reasonably control irrigation costs (Columbia and Dominican Republic).

1.2. Overview of irrigation decentralization history in Vietnam

The decentralization of management and exploitation of hydraulic works for WUOs that have been studied and developed the highest in the current legal document system of Vietnam is Circular No. 65 on "Guiding organization of operation and decentralization of management and exploitation of irrigation works". According to the result of the review in 2014, 55 out of 63 provinces of Viet Nam have developed a project on management and exploitation decentralization of irrigation works as directed by TT65. After 5 years of implementing Circular No. 65 (2010-2015), 39/63 provinces (62%) implemented IMT under the decentralization scheme; The number of hydraulic works transferred are 3,191 reservoirs, 11,500 dams, 7,036 electric
pumping stations, 4,068 culverts and tens of thousands of channels at all level. Particularly, the Mekong Delta has decentralized: 13/14 reservoirs, 2,327/3,127 electric pump stations, 3,503 culvert drains and 12,715/67,183 km of canals [49].

1.3. Overview of criteria to support irrigation decentralization

1. Decentralization criteria in accordance with the work levels:

According to experience, experts will mark and classify the hydraulic works into different level (from high to low) on a irrigation map (scale of 01 irrigation area or 01 territory); Based on the above classes, decentralize the tasks to WUOs. Specifically in Japan:

**Figure 1.5.** Decentralization in accordance with work level in Japan.

*Source: Japanese Institution of Irrigation Research, 2007*

In which:

- Type A: the on-farm irrigation works (canals, ditches, sluices to supply water to the field, water level, water trough, etc.).

- Type B: the hydraulic works at small focal levels (canal culvert, main canal, level 1 and 2 or higher level).

- Type C: the hydraulic works at larger focal levels (dams, reservoirs, pumping stations, culverts and tidal sluice gates).

- Type D: the hydraulic works at national level (hydropower reservoirs, big dams, multi-purpose reservoirs, etc.).
The advantage is that it is possible to perform decentralization on a large irrigated area [20], [52]; disadvantage is that it is very difficult to find the subject management of each level of irrigation works.

2. **Decentralization criteria in accordance with the development of irrigation organizations:**

   According to the research results conducted by PIM Consulting Center-VAWR in 2007 in the Mekong Delta, the development of some typical types of WUOs is as follows:
   - Level 1- Households or groups of households using water.
   - Level 2- Irrigation service groups.
   - Level 3- Cooperative groups.
   - Level 4- Agricultural cooperatives or WUGs.
   - Level 5- Inter-commune Irrigation Management Board.

   Based on the hierarchy of irrigation system development organizations, countries such as Thailand, the Philippines, Nepal, etc. have allocated grade 3 interior field irrigation work to grassroots irrigation institutions for direct management.

   The advantage is that it is of high reliability and weakness is that it is difficult to apply to the existing irrigation systems lacking grassroots irrigation management organizations.

3. **Decentralization criteria in accordance with the irrigation area:**

   In the world, the area of irrigation, rice cultivation (hectare, km²) is currently one of the legal bases for decentralization to WUOs, including Vietnam. The irrigated area for decentralization differs in each country. For example, the Dominican Republic proposes decentralization of hydraulic works with service area of \([ \leq 1,000 \text{ ha} ]\); Ghana's Volta basin is \([ \leq 100 \text{ ha} ]\), Indonesia is \([ \leq 500 \text{ ha} ]\); Mountainous areas of Nepal is \([ \leq 500 \text{ ha} ]\) and plain is \([ \leq 2,000 \text{ ha} ]\); Zimbabwe is \([ \leq 80 \text{ ha} ]\); The Philippines is \([ < 1,000 \text{ hectares} ]\); Taiwan is \([ < 270 \text{ hectares} ]\).

   The advantage is that it is possible to perform decentralization on a large irrigation area, but there is no basis yet to determine whether
the irrigation area as described above is appropriate or not with management and exploitation of WUOs.

4. **Decentralization criteria in accordance with the levels O&M:**

The evaluation of the levels from simple to complex of operation and maintenance (O&M) of each type of hydraulic works is based on:

- The level of hydraulic works operation such as: (i) Operating and distributing; (ii) During drought, saline intrusion; (iii) Regeneration of water after irrigation back to the irrigation system.

- The level of hydraulic maintenance: capacity and skills of repairing and maintaining hydraulic works of the WUOs to meet the complex operation requirements of these hydraulic works.

According to R.R. Javier and H. Kuscu, the assessment of capacity and experience in O&M can be based on the satisfaction of the quality of irrigation services of water users under KIS method including 01 dependent variable Y (irrigation service quality) and 05 independent variables Xi (O&M operation):

\[
P_i = E \left( Y = \frac{1}{X_i} \right) = \frac{1}{1+e^{(\beta_1 + \beta_2 X_i)}} \rightarrow L_i = \ln \left( \frac{P_i}{1-P_i} \right) = \beta_1 + \beta_2 X_i \quad (I-I)
\]

5. **Decentralization criteria in accordance with the administrative boundaries:**

By statistically compiling and cataloging all irrigation works within the administrative boundary of the administrative unit of a province, district, commune or village, the competent authority shall make a decision on the implementation of the IMT to the WUOs participating in management and exploitation of hydraulic works, usually the hydraulic works in one commune or 01 village.

Advantage is that this is the fastest support criteria to complete the implementation of IMT for WUOs in short time, but very difficult to apply to the irrigation systems with many inter-district and inter-communal hydraulic works.
6. Decentralization criteria in accordance with the number of intake points on the canals:

This is a solution for inter-provincial and inter-district canals which are located in areas with complex terrain, difficult to manage. For example, in Thabina, Limpopo province of South Africa, decentralized in accordance with the plan that every 04 intake points on the canal is managed by a WUGs.

However, this is not a criterion that can be applied universally to many different regions because it only meets the needs of irrigation decentralization for the type of canal work.

1.4. Overview of irrigation performance assessment methods

- Rapid Assessment Procedures (RAP/MASSCOTE).
- Benchmarking Assessment Method.
- Method of evaluating the efficiency of on-farm irrigation works.
- Method of evaluating general economic efficiency.

However, after the pilot application in some localities, the collection of data, information is quite complex, multi-dimensional; many indicators lack scientific basis and are not suitable with the specific conditions of irrigation of the regions and areas; these methods are not suitable for use in the QL-PH irrigation system.

1.5. Overview of decentralized irrigation in research area

QL-PH consists of three main sub-zones: (i) Quan Lo-Phung Hiep; (ii) Ba Rinh-Ta Liem; (iii) Tiep Nhat. Natural land area is about 403,000 hectares. Particularly, Ql-PH has about 430,000 water users and 300,000 ha of agricultural production land.

To implement IMT for grassroots irrigation organizations, the QL-PH area has applied 3/6 criteria to support the decentralization of management and exploitation of irrigation works, namely: (i) irrigation work level; (ii) administrative boundaries; (iii) complexity of O&M of hydraulic works. Statistics in 2/5 provinces of QL-PH irrigation system is shown in Table 1.13.
Table 1.3. Some bases of decentralizing the management and exploitation of irrigation works in QL-PH area

<table>
<thead>
<tr>
<th>No.</th>
<th>Province</th>
<th>Work scale</th>
<th>Canal level</th>
<th>Administrative boundaries</th>
<th>Degree of complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hau Giang</td>
<td>IDMC Large and medium</td>
<td>Inter-district, inter-commune</td>
<td>Complex</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WUOs</td>
<td>Small</td>
<td>01 commune</td>
<td>Simple</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Bac Lieu</td>
<td>IDMC Large</td>
<td>1 and 2</td>
<td>Inter-district</td>
<td>Complex</td>
</tr>
<tr>
<td></td>
<td>WUOs</td>
<td>- Sewer systems</td>
<td></td>
<td>01 village, 01 commune, inter-commune</td>
<td>Simple</td>
</tr>
</tbody>
</table>

Source: IWEM-VAWR, 2015

1.6. Identifying the problem to be studied

In order to support the decentralization of irrigation management and exploitation effectively and sustainably in the QL-PH area, the nature of the problem to be solved is to evaluate the capability of receiving management and exploitation of irrigation works of the WUOs, but also need to aim to improve the efficiency of exploitation of irrigation works.

CHAPTER 2: BUILDING SUPPORT METHODS OF DECENTRALIZED IRRIGATION MANAGEMENT FOR WATER USER ORGANIZATIONS

2.1. The rationale of the problem to be researched and perception

The WUOs is defined as the organization of water users, accordingly the nature of evaluating the receiving capability of WUOs is the assessment for water users. However, capability is the concept
that is primarily used for business entities; For individuals, the concept of perception is used. Arguments results made initial comments is that to have efficiency in exploiting irrigation works, water users (WUs) need to have a good perception of irrigation works.

2.2. Research hypothesis

1. The efficiency of irrigation work exploitation depends on the perception of hydraulic works of water users; some assumptions that crop varieties, cultivation techniques, fertilizer application and other market factors, etc. affect the exploitation efficiency of irrigation works, which is negligible.

2. The value of the irrigation work exploitation is directly proportional to the perception of hydraulic works of water users.

2.3. Research approach

Figure 2.3. Approach methodology in decentralization of irrigation works based on water users’ perceptions.
Proposing block diagram of algorithm model of method to support the decentralization as shown in **Figure 2.4**: 

![Diagram of algorithms in ALGORITHMS MODEL.](image)

**Figure 2.4.** Diagram of algorithms in ALGORITHMS MODEL.

The sequence of steps is as follows:

1. Evaluating the efficiency of irrigation works exploitation by internal and external indicators [Regulated as dependent variable group (HQi)]; Evaluating perception of hydraulic works of water users [Regulated as independent variable group (NTi)].

2. Analyzing, identifying and clarifying the relationship between the two indicator group of "Efficiency-Perception".

3. Processing data by using IBM-SPSS, regression analysis, optimality with the highest expectations for the exploitation efficiency of irrigation works, then, determine the optimal cognitive points.
4. Basing on the value of these effective and optimal cognitive points to assess the capability of receiving water management and exploitation of water users.

2.4. **Specific methods to support the decentralization of management and exploitation of irrigation works**

1. **The sets of indicators evaluating efficiency and perception**

**Appendix 1**: Meaning of dependent and independent variables.

<table>
<thead>
<tr>
<th>Dependent variables (Y) - Exploitation efficiency of irrigation work</th>
</tr>
</thead>
<tbody>
<tr>
<td>HQ1</td>
</tr>
<tr>
<td>HQ2</td>
</tr>
<tr>
<td>HQ3</td>
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<tr>
<td>HQ4</td>
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<tr>
<td>HQ5</td>
</tr>
<tr>
<td>HQ6</td>
</tr>
<tr>
<td>HQ7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent variables (X) - Perception of hydraulic works of WUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT1</td>
</tr>
<tr>
<td>NT2</td>
</tr>
<tr>
<td>NT3</td>
</tr>
<tr>
<td>NT4</td>
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<td>NT5</td>
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<td>NT6</td>
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<td>NT7</td>
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<td>NT8</td>
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<td>NT9</td>
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<td>NT11</td>
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<td>NT12</td>
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<tr>
<td>NT13</td>
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<tr>
<td>NT14</td>
</tr>
</tbody>
</table>
2. The matrix to support the decentralization under AHP:

Using Analytic Hierarchy Process (AHP) to propose the matrix to support the decentralization; In which, one direction of the matrix is the levels of grassroots irrigation organization or WUOs, the other one is the levels of hydraulic works (1, 2, 3 or interior field) for each type of irrigation works (canals, culverts, pump stations, etc.).

The perceptions values of water uses are indicators of the type of of WUOs and the type of hydraulic works that the water users can accept and directly participate in management and exploitation.

3. Research sample size selection method:

Applying the general formula 2-2:

\[
\begin{align*}
n &= \left[ \frac{1}{N} + \frac{N-1}{N} \times \frac{1}{P(1-P)} \left( \frac{k}{z_{1-\alpha/2}} \right)^2 \right]^{-1}
\end{align*}
\]  

(2-2)

Of which:

- \(N\) - total number of samples in the survey area.
- \(P\) - overall ratio.
- \(K\) - permissible error.

4. Pearson (r) correlation analysis method:

With two variables X and Y of the same sample size n, the Pearson correlation coefficient is calculated as follows:

\[
r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}
\]  

(2-6)

Of which:

- The correlation coefficient is from \([-1 \div 1]\).
- If \((r < 0)\) means that x and y are inversely correlated.
- If \((r > 0)\) means that x and y are positively correlated.
5. *Multivariable objective function optimization method*:

The multi-objective mathematical optimization model on the exploitation effectiveness of irrigation works is expressed as follows:

\[ f(Y) = [X_i; Y(Y_j)] \]  \hspace{1cm} (2-11)

Constraints:

\[
\begin{align*}
& g_h(X) \leq, =, \geq b_h, h=1,2 \ldots m \\
& X \in Z \subset R_n
\end{align*}
\]  \hspace{1cm} (2-12)

Accordingly, with the desire to achieve the highest exploitation efficiency of irrigation work, the function \( f(Y_i) \rightarrow \text{Max} \).

**CHAPTER 3. APPLICATION OF DECENTRALIZATION RESULTS PROPOSED FOR WATER USER ORGANIZATIONS IN QUAN LO-PHUNG HIEP IRRIGATION SYSTEM**

3.1. **Investigation and survey method in Quan Lo-Phung Hiep**

1. The water users’ perception assessment on irrigation works focuses on the subjects including: (i) Individuals; (ii) Households; (iii) Household groups who self supply irrigation services.

2. Scope of survey is the water users who are: (i) at the working age; (ii) in the study area; (iii) randomly selected, distributing by distance across canal levels in 03 provinces of Ca Mau, Soc Trang and Bac Lieu; (iv) not be the staffs of the IDMC; but be participated in the in-depth interviews for information verification.

3. Surveyed and invested sampling design: due to the large served sample size in QL-PH (estimated at 430,000 water users), the sample size applied according to the Cochran formula (1977) with 5% of error expectations and 95% of reliability is:

\[ n = \frac{1,96^2 \times 0.5 \times (1 - 0.5)}{0.05^2} = 384.16 \]

To ensure the representability, the sample size is chosen: \( n = 384 \) samples. Actually, 400 samples have been surveyed.
4. Selection of sampling sites by multi-stage sampling method (Table 3.1).

Table 3.1. Sampling sites in QL-PH irrigation system

<table>
<thead>
<tr>
<th>No.</th>
<th>Canal</th>
<th>Village/Group</th>
<th>Commune/ward</th>
<th>District</th>
<th>Province</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cai Nhuc - Cay Tram</td>
<td>Group 1</td>
<td>Tan Thanh Ward</td>
<td>Ca Mau city</td>
<td>Ca Mau</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Group 2</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>Group 3</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Village 3</td>
<td>Tan Thanh</td>
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<td></td>
<td></td>
<td>Village 4</td>
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<td></td>
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<td></td>
<td>Village 5</td>
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<tr>
<td></td>
<td></td>
<td>Binh Dinh</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>Xang Ca Mau - Bac Lieu</td>
<td>Cai Ro</td>
<td>Dinh Binh</td>
<td>Ca Mau city</td>
<td>Ca Mau</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bung Binh</td>
<td>Hoa Tan</td>
<td></td>
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<td></td>
<td></td>
<td>Bung Binh 2</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>Hoa Dong</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>Pho Sinh</td>
<td>Village 21</td>
<td>Phong Tan</td>
<td>Gia Rai</td>
<td>Bac Lieu</td>
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<td></td>
<td></td>
<td>Village 15</td>
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<td></td>
<td>Village 14</td>
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<td></td>
<td></td>
<td>Village 20</td>
<td>Phong Thanh</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Village 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Quan Lo - Nhu Gia</td>
<td>4.1 Xang My Phuoc</td>
<td>Tan Lap B</td>
<td>Long Tan</td>
<td>Nga Nam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.2 Quan Lo - Nhu Gia</td>
<td>Phuoc Ninh</td>
<td>My Phuoc</td>
<td>My Tu</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Phuoc An B</td>
<td>My Thuan</td>
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<td>Phuoc An A</td>
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<td></td>
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<td></td>
<td>Phuoc An</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Nguyen Duc Viet and local irrigation officers, 2014

5. Data collection methods:
- Data verification method.
- Interview method.
- Direct measurement method: using some salinity measurement instrument (such as HANNA HI 9835, AZ8602, EXTECH EC170...) to recognize and correctly salt concentration (‰).
3.2. Survey results of Quan Lo-Phung Hiep irrigation system

1. Evaluating the objectivity and rationality of the water users’ perception assessment indicators of hydraulic works:
   - The foundation for evaluating the objectivity and rationality of perception indicators is the people’s perception about a thing or an event depending on the observation distance of the subject [91], [92].
   - The selection of variable D.KC1 mean that “Distance from the water users’ water receiving position to the intersection between primary and secondary canals” is a simulation variable for determining the objectivity for 14 perception assessment indicators.
   - Data collection in QL-PH irrigation system based on the survey design and use of IBM-SPSS software for analyzing the relationships among 14 perception assessment indicators and variable D.KC1.

   A specific example for the indicator NT1: the water user's perception of key irrigation work (Figure 3.2).

   **Figure 3.2.** Diagram NT1 perception distribution by distance.

   This result is entirely in line with the practice in QL-PH because the locations of the key irrigation works are the salt-water preventing and fresh-water retaining sewers usually located at the end of the secondary canals.

2. Correlation analysis:
- There are 9/14 cognitive assessment indicators and Pearson (r) > 0.2 and Sig. (2-tailed) < 5%; thus, there is a correlation between 9/10 of this cognitive variable (NT) with three efficiency assessment indicators inside irrigation work exploitation (ID_HQ).

- A similar analysis of 3/4 efficiency assessment indicators outside irrigation work exploitation (ED_HQ) (ED_HQ2 has no data) shows that 9/14 indicators have a correlation; only NT1 and NT9 will be excluded from regression analysis with variables ED_HQ4.

3. Reliability testing according to Cronbach's Alpha: 10/14 remaining indicators have the corrected item - total correlation which is greater than 0.4 (from 0.810 ÷ 0.872). They continue to be put into the correlation analysis.

4. Regression analysis between exploitation effectiveness of irrigation works and water users’ perception by IBM-SPSS software:

![Figure 3.13. Correlation analysis via IBM - SPSS.](image)

Because it is a new study, it is necessary to run regression of different line types (Figure 3.14), then select the most appropriate path to simulate the data sample.
<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>107790.124</td>
<td>9</td>
<td>11976.680</td>
<td>34.329</td>
<td>.000</td>
</tr>
<tr>
<td>Residual</td>
<td>130480.121</td>
<td>374</td>
<td>348.877</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>238270.246</td>
<td>383</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: Effectiveness of repair and maintenance irrigation works.

ANOVA analysis shows that the conditions of the VIF coefficients are equal to [<2] and Sig <5%, using the coefficients of the regression equation as follows:

- Effectiveness of the level 3 irrigation work and on-farm canal maintenance (ID_HQ1):
  \[ Y_1 = 2.170 + 1.437X_1 + 1.873X_2 + 2.574X_3 + 1.012X_4 + 1.686X_5 - 0.249X_6 + 2.342X_7 + 0.221X_8 + 3.162X_9 \text{ (3-1)} \]

- Effectiveness of level 3 irrigation work operation (ID_HQ2):
  \[ Y_2 = 0.395 + 1.023X_2 + 2.048X_3 + 0.575X_4 + 0.088X_6 + 0.030X_8 + 0.387X_9 \text{ (3-2)} \]

- Effectiveness of level 3 irrigation work protection (ID_HQ3):
  \[ Y_3 = 2.4 + 0.69X_1 + 0.070X_2 + 1.150X_3 + 0.230X_4 + 1.090X_8 + 0.612X_9 \text{ (3-3)} \]

- Effectiveness of on-farm work service quality (ED_HQ1):
  \[ Y_4 = 4.041 + 1.490X_2 + 1.369X_3 + 3.897X_4 + 0.552X_5 + 2.334X_7 + 1.139X_8 + 3.389X_9 \text{ (3-4)} \]

- Effectiveness of products per farming unit (ED_HQ3):
  \[ Y_5 = 1.278 + 0.113X_1 + 0.013X_2 + 0.017X_3 + 0.398X_4 + 0.231X_6 + 1.101X_8 + 0.258X_9 \text{ (3-5)} \]

- Effectiveness of adaptation of salinity intrusion:
  \[ Y_6 = 2.581 + 0.040X_2 + 0.183X_4 + 0.039X_8 + 0.039X_9 \text{ (3-6)} \]
5. Calculation results of water user’ perception optimization:

Figure 3.14. Regression analysis line (predicted) between the effectiveness of irrigation work exploitation and the water users’ perception of hydraulic work.

Expression of multi-objective function (multi-variables) on the effectiveness of irrigation work exploitation:

Objective function (Objective): $f(Y) = [NT_1; \ Y(HQ_i)] \rightarrow \text{MAX or MIN} \ [-f(Y)];$

Constraints:

\[
\begin{align*}
0.54 \leq NT_1 & \leq 3; \\
1.16 \leq NT_2 & \leq 3; \\
0.82 \leq NT_3 & \leq 4; \\
1.78 \leq NT_4 & \leq 4; \\
1.36 \leq NT_6 & \leq 4; \\
0.80 \leq NT_7 & \leq 4; \\
0.85 \leq NT_9 & \leq 4; \\
1.13 \leq NT_{10} & \leq 4; \\
1.36 \leq NT_{11} & \leq 3; \\
NT_4 - NT_6 & \geq 0 \\
NT_{10} + NT_{11} - NT_6 & \geq 0 \\
NT_1 \leq NT_2 \leq NT_3 & \leq NT_4
\end{align*}
\]

MATLAB

```matlab
%% Multi-objective Optimization between Awareness and Efficiency
% Find min -[-f(x)] = - max [f(x)] values of functions f1, f2, f3, f4, f5, f6
% f1 = x(1); f2 = x(2); f3 = x(3); f4 = x(4); f5 = x(5)
% f6 = x(6); f7 = x(7); f8 = x(8); f9 = x(9);

%% Constraint function
% NT_1 < NT_2 < NT_3 < NT_4
% x(1) = x(2) + x(3) + x(4) + x(5) + x(6) + x(7) + x(8) + x(9);< 0
% x(1) + x(2) + x(3) - x(4) + x(5) + x(6) + x(7) + x(8) + x(9); < 0
% NT_4 - NT_6 < 0
% x(1) + x(2) + x(3) + x(4) + x(5) - x(6) + x(7) + x(8) + x(9); < 0
% NT_10 + NT_11 - NT_6; > 0
% x(1) + x(2) + x(3) + x(4) + x(5) + x(6) + x(7) - x(8) - x(9); < 0

%% Matlab Code
>> A = [-1 -1 0 0 0 0 0 0 0];
>> b = [0 0 0 0 0 0];
>> Ab = [1.2 1.3 1.4 1.5];
>> f1 = [-1.497 -1.873 -2.574 -1.052 -1.684 -0.249 -2.342 -0.221 -3.162]
>> d1 = 2.179
>> [x_f, fval] = fminsearch(f1,Ab,[]); % max of function f1
>> T_TO_HQ_max = fval + 20.170 % function f1 + offset 20.170
```

...
Of which, the lower boundary values [0.54, 1.16, 0.82, 1.78, 1.36, 0.80, 0.85, 1.13, 1.36] of $X_i$ are mean values of water users’ perception of hydraulic works in QL-PH; the upper boundary values of $X_i$ are based on the measurement scale of the indicator set.

Solving multi-objective functions 3-7 based on the the fuzzy sets by MULTIOPT 2.0 and MATLAB R2015a software gives three scenarios of function $(u)_{\text{max}}$ according to the top-down order as Table 3.21.

**Table 3.21.** Optimal calculation results for each scenario

<table>
<thead>
<tr>
<th>Variable code</th>
<th>$X_1$</th>
<th>$X_2$</th>
<th>$X_3$</th>
<th>$X_4$</th>
<th>$X_5$</th>
<th>$X_6$</th>
<th>$X_7$</th>
<th>$X_8$</th>
<th>$X_9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception</td>
<td>NT1</td>
<td>NT2</td>
<td>NT3</td>
<td>NT4</td>
<td>NT6</td>
<td>NT7</td>
<td>NT9</td>
<td>NT10</td>
<td>NT11</td>
</tr>
<tr>
<td>SCENARIO 1</td>
<td>$w_1 = w_2 = w_3 = w_6 = 0.2$ và $w_4 = w_5 = 0.1$</td>
<td>0.77</td>
<td>1.46</td>
<td>1.76</td>
<td>2.78</td>
<td>3.36</td>
<td>2.15</td>
<td>0.85</td>
<td>3.13</td>
</tr>
<tr>
<td>Optimization</td>
<td>1.46</td>
<td>1.46</td>
<td>1.76</td>
<td>2.00</td>
<td>2.36</td>
<td>1.15</td>
<td>1.85</td>
<td>2.33</td>
<td>3.63</td>
</tr>
<tr>
<td>Proposed level</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>SCENARIO 2</td>
<td>$w_1 = w_2 = 0.1$ và $w_3 = w_4 = w_5 = w_6 = 0.2$</td>
<td>1.77</td>
<td>2.25</td>
<td>2.11</td>
<td>1.78</td>
<td>1.16</td>
<td>1.15</td>
<td>0.85</td>
<td>1.13</td>
</tr>
<tr>
<td>Optimization</td>
<td>1.77</td>
<td>2.25</td>
<td>2.11</td>
<td>1.78</td>
<td>1.16</td>
<td>1.15</td>
<td>0.85</td>
<td>1.13</td>
<td>2.63</td>
</tr>
<tr>
<td>Proposed level</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>SCENARIO 3</td>
<td>$w_1 = w_2 = w_3 = w_6 = 0.1$ và $w_4 = w_5 = 0.2$</td>
<td>1.46</td>
<td>1.76</td>
<td>2.00</td>
<td>2.36</td>
<td>1.15</td>
<td>1.85</td>
<td>2.33</td>
<td>3.63</td>
</tr>
<tr>
<td>Optimization</td>
<td>1.46</td>
<td>1.76</td>
<td>2.00</td>
<td>2.36</td>
<td>1.15</td>
<td>1.85</td>
<td>2.33</td>
<td>3.63</td>
<td></td>
</tr>
<tr>
<td>Proposed level</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Based on the factors of socio-economic development in QL-PH area, the selection of 01 optimal scenario for water users’ perception should ensure the the following factors:

- Support in perception raising training: Three scenarios meet this factor, of which, the scenario 01 has the highest increase value.
- Socialization of irrigation: Three scenarios meet this factor, but the scenario 03 has the weakest value change.
- Ability of water users’ exploitation receiving of irrigation work: only the scenario 01 and 02 meet the logic of this factor.

In summary, after the specific conditions of the irrigation works and the practice of agriculture production in QL-PH irrigation system are compared and analyzed, the SCENARIO 01 is the optimal option for further analyzing the proposed decentralization (Table 3.22).
Table 3.22. Comparison between the optimal perception results and current situation

<table>
<thead>
<tr>
<th>Perception</th>
<th>Current situation</th>
<th>Optimal result</th>
<th>Proposed level</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT1 = X₁</td>
<td>0.54</td>
<td>0.77</td>
<td>1</td>
</tr>
<tr>
<td>NT2 = X₂</td>
<td>1.16</td>
<td>1.46</td>
<td>1</td>
</tr>
<tr>
<td>NT3 = X₃</td>
<td>0.82</td>
<td>1.76</td>
<td>2</td>
</tr>
<tr>
<td>NT4 = X₄</td>
<td>1.78</td>
<td>2.78</td>
<td>3</td>
</tr>
<tr>
<td>NT6 = X₅</td>
<td>1.36</td>
<td>3.36</td>
<td>3</td>
</tr>
<tr>
<td>NT7 = X₆</td>
<td>0.80</td>
<td>2.15</td>
<td>2</td>
</tr>
<tr>
<td>NT9 = X₇</td>
<td>0.85</td>
<td>0.85</td>
<td>1</td>
</tr>
<tr>
<td>NT10 = X₈</td>
<td>1.13</td>
<td>3.13</td>
<td>3</td>
</tr>
<tr>
<td>NT11 = X₉</td>
<td>1.36</td>
<td>3.63</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 3.15. WU’ optimal perception trend of hydraulic works.

The diagram illustrated in the Figure 3.15 shows that the multi-objective (multivariable) function will be highest when:

- Water users should be aware of irrigation water for agriculture production from the irrigation works system (variable NT6).

- Water users know how to organize, operate and distribute water continuously from the top of level 3 canal to farm, need to solve conflicts may occur during the process of water distribution (NT10).
- Water users know how to self maintain, repair and protect the small hydraulic works, interior field irrigation (variable NT11).

- There are 7/9 perception indicators have the higher value compared to that at the time of research conducted; 2/9 indicators which have the constant value is the perception of different canal level (NT2) and irrigation costs affecting the service quality (NT9).

Accordingly, along with the development of grassroots irrigation organizations in QL-PH from grade 1 → grade 5, the decentralization support matrix approach proposed for assigning management tasks is applied and each type of hydraulic work is exploited in accordance with each type of WUOs.

CONCLUSION AND RECOMMENDATIONS

1. Conclusion:

The study has completed a method to support the decentralization of management and exploitation of irrigation works for WUOs in QL-PH irrigation system meeting the requirements of a new scientific method including six main contents as follows:

- Methodology: The perception criterion were chosen to be a new one for studying the decentralization in addition to the existing criteria such as irrigation work grade, irrigation area, drainage area, administrative boundaries, number of water intake point, etc.

- Research approach: Based on the socio-economic development situation in Vietnam, the research has selected a bottom-up approach to implement the proposed decentralization in QL-PH irrigation system. Accordingly, the comprehensive process combining sets of indexes and algorithms is also proposed.

- Specific method: Applying the fuzzy set theory to convert six above single objective functions \([3-1]\) to \([3-6]\) into one multi-objective (multivariable) function with some constraints according to the characteristics of QL-PH, applying the simplex algorithm integrated in
The result of exploratory factor analysis by decentralization support method also answers 02 research hypotheses as follows:

- The Pearson (r) indicator from 0.65 to 0.7, meaning that about 65-70% of the fluctuation of an exploitation effectiveness indicator can be explained by WU’ perception indicators of hydraulic works.

- The effective value of the irrigation work exploitation (Xi) is directly proportional to the WU’ perception (Y), when the Xi values increase, the total value of fval (Y) increases and vice versa.

2. Recommendations:

From the intuitive results under the decentralized support matrix, there are some specific decentralization recommendations in QL-PH as follows:

- At the time of the study conducted (in 2014): the type of WUOs recommended for development is the household /household group using water and the irrigation service group (3-5 people). They are assigned to manage and exploit: (i) Level 3 canal and interior field; (ii) Level 3 head regulator, interior field; (iii) Interior field small pumping station (5-30 hectares).

- According to the optimal scenario, the following 4 types of irrigation organizations should be promoted: (i) Households / groups of households using water; (ii) Service team; (iii) Cooperation groups; (iv) Agricultural cooperatives or water using cooperatives. Depending on each specific exploitation task, the competent authority will allocate the corresponding types of irrigation works.

- In order to achieve the optimal scenario (after decentralization) at QL-PH irrigation system, it is necessary to improve the capacity of irrigation management and exploitation of irrigation works, riseing the awareness about the work of the WUs./.
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