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Groundwater recharge through shallow groundwater recharge system by infiltration ponds in Fai Kwang Sub-district, Phayao Province of Thailand

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Abstract

The shallow groundwater recharge at an area scale in Fai Kwang Subdistrict, Chiang Kham District, Phayao Province, Thailand aim to apply of the groundwater replenishment system to solve the problem of drought and insufficient water for consumption using by shallow groundwater recharge system through the concrete circle in pond integrating with using technology to manage surface water with the GIS system and geophysical surveys for evaluating the potential of groundwater resources to access information on land use, soil conditions, water resources. The groundwater recharge system at depth 12 m and water was replenishment occurs flow from pubic pool collected water converted to water filtration and pumping average water volume of 3.54 m3/hr to solve the problem of surface water quality for water supply in tap water production of Siwilai Village, Fai Kwang Subdistrict, Phayao Province, which enabled people in the area to used water for 200 homes. The social return on investment (SROI) was 59.23%, reducing water purchase and medical expenses due to water quality impact. The study results have led to the creation of water management policies and the application of information and innovations for drought resolution. Measures and requirements for using public water sources for consumption collecting income for the maintenance of the village's water supply system.

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KEYWORDS: groundwater recharge, infiltration pond, geophysical surveys, soil conditions, SROI, Phayao Province.

INTRODUCTION

Fai Kwang Subdistrict, Chiang Kham District, Phayao Province of Thailand is characterized by a flat area at the foot of the mountain with mountains lying to the south and west. The slope is flat from the middle to the north. The Van River flows from the south to the north and the Lao River flows from the way east to the west, making the plains suitable for agriculture, cultivation, plantations, and gardens.The sub-district has a Van Khong Reservoir, an area of 0.145 km2, and a Van Reservoir, an area of 0.12 km2. Kwang Dam consists of 17 villages, 3,719 households, and a population of 8,812 people with a total area of 167 km2, classified as residential. 6.81 km2 of farm animals of 18.13 km2, 14,624 km2 of farmland, 2.79 km2 of public land, 2.59 km2 of empty land 14.62 km2 of rice fields, 9.80 km2of gardens, 0.55 km2of fishing, and 88.38 km2 of forests. Fai Kwang sub-district has 45.73 km2 of repetitive drought or 28.39 percent of the area. People in the area suffer from water shortage during the dry season due to climate change. A decrease in annual rainfall with a concentration of precipitation during the rainy season causes insufficient water for cultivation and consumption, resulting in lower crop yields and damage to cultivated land. 8 km2 caused approximately 30,000 dollars in economic damage to the subdistrict of Fai Kwang. The assess the situation by engaging with the community through the SWOT analysis process, allowing the community to know the strengths of areas with natural water sources and built water sources in some sub-district areas. There is a water management committee in each village. The weaknesses found are that There are no reservoirs in some areas and reservoirs built in some areas could be more efficient. Inability to store water, Unable to draw water from natural water sources. It can be used because the topography is upland Lack of water storage and water distribution systems in the dry season Obstacles in water management in the area come from the need for more funding to support the development of water management structures. Water storage and maintenance lack of direct coordination with provincial agencies area development law which is a conservation area, Including obstacles to the geology of the area with little water storage. As for the opportunity, it was found that There is a public area ready to construct a reservoir. Water is transported from the municipality during the dry season. In addition, the country's water management policy focuses on building a groundwater replenishment system and using groundwater for agriculture. Groundwater in Thailand is stored or accumulated in the rocks both types of groundwater are provided, i.e., sedimentary rock, loamy rock, and hard rock. Each year, additional water will seep into the groundwater system from the rainfall that falls each year, about 10 percent of the annual average rainfall, and allow groundwater development to be used up to no more than 10 percent. Allowed to develop to bring up groundwater to use not more than 75% of the stored water volume. The Northern of Thailand, the total amount of groundwater developed is 7,484 hm3, the amount of groundwater that can be used is 5,613 hm3, the amount of groundwater used is 4,577 hm3, the amount of groundwater remaining is 1,036 hm3/yr, the amount of groundwater that can be utilized will be used for consumption water, agriculture and industry. In the area of the groundwater basin province, Chiang Rai - Phayao, an area of 15,022.39 km3 and the groundwater storage volume was 21,822.29 hm3, with an increase in water volume of 1,829.23 hm3/yr. The groundwater well of Fai Kwang Municipality, Chiang Kham District, Phayao Province, was obtained from the groundwater well database of the Department of Groundwater Resources, it was found that there were a total of 17 underground wells located in Fai Kwang sub-district. The wells that could be used for water consumption, with an average drilling depth of 46.37 m, an average development depth of 47.24 m, and an average water volume of 3.54 m3/hr. The average normal water level is 6.34 m.

The water table depth (WTD) of shallow aquifers in many non-humid parts of the world, such as the high plains of the United States, the Ganges Plain of India, the Middle East, North China, and Northwest China, is often relatively significant due to natural physical factors and human activity. The expansion of civilization and business has led to the overexploitation of groundwater resources in several water systems [1].

In just the past few years, exceptional interest for groundwater recharge has been emeraged [2], [3] Groundwater storage balance is input-output. Precipitation, surface water irrigation, and regulated aquifer recharge are inputs. Natural discharge (streams, lakes, and the ocean in coastal aquifers; evapotranspiration) and anthropogenic pumping are outputs [4] Recharge methods are essential for replenishing groundwater storage. Managed, unmanaged, and inadvertent (e.g., profound seepage under irrigation) [5]. Infiltration basins and well-directed injection are managed procedures[5], [6]. Drainage wells and septic tank leaching are unmanaged systems for water disposal without recovery or reuse [5]. Managed aquifer recharge (MAR) involves actively diverting, transporting, storing, infiltrating, and recharging excess surface water into aquifers during wet periods for dry periods or environmental gain [4], [5], [7], [8]. The main goals of MAR are (1) storage of excess water during the wet period for later use in dry periods (mainly in arid/semi-arid regions); (2) the introduction of a water treatment barrier (improving water quality for future specific use); (3) the creation of a hydraulic barrier that prevents seawater intrusion (e.g., in coastal regions) [9] and (4) flood control [10]. MAR technologies and configurations vary based on the recovered water's application (e.g., drinking, irrigation, hygiene, ecosystem support, industrial water, and recreation) [11]. The benefits of groundwater replenishment include:1. Restoration of groundwater sources solves the problem of decreasing groundwater levels. 2. Alleviate flooding problems, reduce the problem of flooding in the community, and reduce damage during the flood season. 3. Solve drought problems water-filled underground can be pumped up for use during the dry season or the shortage of water. 4. Prevent the intrusion of salt water. When the groundwater level rises, there is enough pressure to push saltwater farther from shore. 5. Reduce the cost of subsidence of the well. The groundwater level has recovered. Therefore, there is no need to dig a bottomless well.

The groundwater augmentation technology was deployed in problems in Fai Kwang. Surveying land use, precipitation, and geophysical data provided decision-making information on the use of groundwater aeration systems to solve problems, aThe socio-economic impacts were assessed by social return on investment (SROI) after the establishment of the groundwater recharge system.

METHOD

1. Survey land use information included average rainfall in the past ten years, annual rainfall, data of water sources, groundwater condition in Fai Kwang sub-district, Chiang Kham District, Phayao Province.

2. The survey area is Fai Kwang Sub-district, Chiang Kham District, Phayao Province, located at coordinates in the UTM system 639759E/2152799N, zone 47Q. Geophysical data by electrical resistivity survey method Vertical Electrical Sounding (VES) within a radius of 1 kilometer. The processing steps are as follows:

   a) Set the default value by specifying the number of soil layers. Resistivity and the thickness of each soil layer were estimated.
   b) Calculate and compare the theoretical data and the apparent resistivity data (Matching Curve).
   c) Interpret results into geoelectrical model graphs (Geoelectrical Model), where the model shows the depth, thickness, and resistivity of each soil layer.

Specific survey results for each point were interpreted from raw survey data. Resistance in the field all data has been recorded in the resistivity measurement survey form.

Specifically with the Schlumberger polarization method (Schlumberger configuration) by interpreting the data of geophysical surveys to derive additional thematic layers of surface parameters such as resistivity, aquifer thickness, and each specific point obtained information on actual depth, accurate thickness, and true specific electrical resistivity interpreting to The characteristics of each soil layers, rock layers, and rock formations at actual depth.

3. Set up a shallow underground water recharge system through a concrete ring well. The groundwater filling system used to solve the problem is the water filling system through the concrete circle well. (with filtration system) a method for collecting rainwater and runoff.

The shallow groundwater filling system through the concrete ring consists of:

a) a water-filling well (concrete ring well),
b) a gravel sand filtration system between the outer ring and the inner ring well, and
c) a drainage channel or conduit enters the pond to fill with water

4. Social return on investment (SROI)

4.1 Stakeholder analysis combined with social network analysis determine the scope of the assessment and identify stakeholder groups include:

1. Faikwang Subdistrict Municipality Administrators Director of Fai Kwang Subdistrict Municipality Technician Division

2. Community leaders, Civilai Village, Fai Kwang Subdistrict

3. Water user groups Civilai Village, Tambon Fai Kwang

4. Shops in the community

5. Network partners

4.2 Analyze the outcome mapping by showing the link between the project's inputs, activities, outputs, and outcomes.

4.3 Determine indicators whether the results occurred or not and the size of the results?

4.4 Consider various issues, including the proportion of changes that occur as a result of the project (Attribution) and the possibility that some of the results may occur by themselves. Even if there is no project or organization working in this area (Deadweight), the possibility that some of the results may not be incremental. But instead of other results (Displacement)

4.5 Financial valuation of outcomes from the project using the Financial Proxy when getting the value of the change arising from the project in a picture of money

4.6 Net Present Value Calculation of the value of benefits arising from Project implementation (PVB) includes calculating the net present value of the investments invested in the project. Calculate the social return on investment (PVC) to estimate the value of the outcomes SROI by uses financial approximations.

RESULTS AND DISCUSSION

Water resources and water volume and land use utilization

Most land use in Fai Kwang sub-district is an agricultural area of 69.57 Km2, a forest area of 30.33 Km2, a community area of 4.04 Km2, and a water source area of Km2. The average rainfall in the past ten years (2010 - 2020) is 1,282.9 mm and the number of rainy days is 2.51. Averaging from 112 days, rainfall from January 2011 - July 2021 equals 769.8 mm. Water demand for consumption in Fai Kwang Sub-district is 470,120 cubic meters per year. Types of water sources are streams 3 sources, farm wells 17 sources, household wells 192 sources, weirs 6 sources, reservoirs 5 sources, artesian wells 17 sources, a total of 241 sources. The water for planting was 62,659,133 m3 per year. It was founded that rubber cultivation required the most water used at 47,337,600 m3 per year, followed by rice fields was 9,340,455 m3 per year, most of which relied on rainwater for cultivation.

Groundwater potential and direction of groundwater flow

Geological conditions

From the geological map of Phayao Province, which the Department of Mineral Resources prepared in 2007 on the geological features of the exploration area and its vicinity Geology of Phayao Province is supported by sedimentary and metamorphic rocks as follows:

1) Water-conducting sediments (Qa) consist of gravel, sand, silt and clay accumulated in channels, ridges, rivers, and flood basins.

2) Sediment (Qt) consists of gravel, sand, silt, clay and laterite.

3) Red sandstone and mudstone

4) Red rounded scree red brown sandstone interspersed with shale and mudstone

5) Rhyolite, rhyolytic tuff and the Andesitic tuff

Groundwater condition

From the groundwater map of Phayao Province of the Ministry of Nature and Environment, Department of Resources, groundwater in and around the survey area mainly consists of groundwater layers in loose rocks. (Unconsolidated Aquifers) as follows ;

1) High riverbed sediment (Qht) consists of gravel, sand, silt and clay.

Groundwater is stored in gravel layers. accumulated in the area of the low riverbed, the depth of the groundwater layer between 15 - 30 meters

2) Rock strata that provide water to high river sediment (Qht), consisting of gravel, sand, silt and clay. Sandy Groundwater is stored in gravel layers. Accumulated in the area of the high riverbed layer depth. Groundwater is between 20 - 40 meters.

From the groundwater wells database of the Department of Groundwater Resources, Fai kwang Sub-district, Chiang Kham District, Phayao Province has17 underground wells in total.It is an underground well that can be used for consumption and is fresh water with an average drilling depth of 46.37 meters, an average development depth of 47.24 meters, an average water volume of 3.54 cubic meters/hour, and an average normal water level of 6.34 meters.

Geophysical cross-sectional survey results display (Pseudo cross section)

Schlumberger electrode placement Data from the interpretation of each survey point of the Schlumberger electrode placement method Can be displayed in the form of a geophysical pseudo cross section for all two main lines, Line 1 through VES-01 and VES-02 and Line 2 through VES-03 and VES. -04 (Figure 1. and Figure 2.)

Figure 1. Geophysical cross section (Pseudo cross section) Passed survey points VES-01 and VES-02.

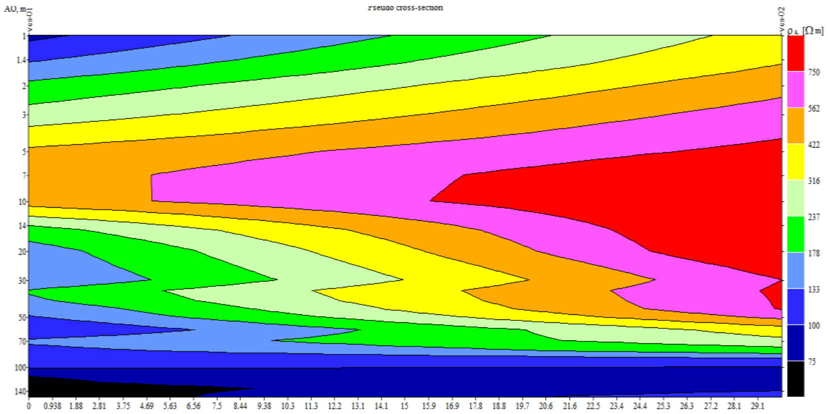
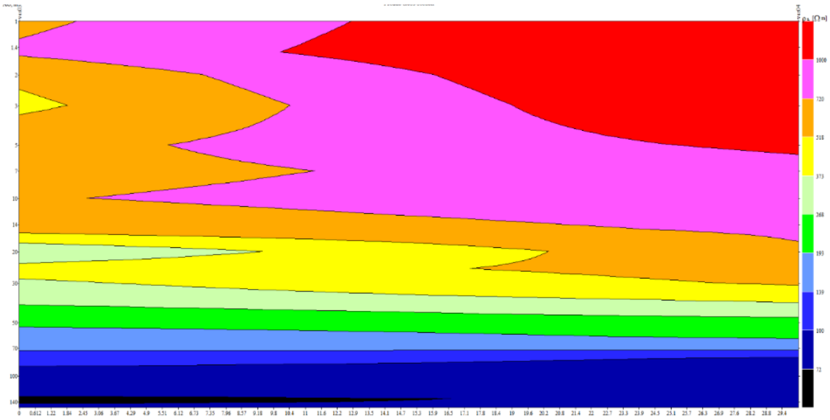
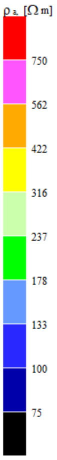


Figure 2. Geophysical cross section (Pseudo cross section) Passed survey points VES-03 and VES-04.



From the survey results of the vertical specific electrical resistivity measurements at all 4 points in the survey area at Fai Kwang Sub-district, Chiang Kham District, Phayao Province. Summary of survey results and interpretation of rock layer classification areas of Fai Kwang Sub-district are shown in Table 1 and 2 as follows.

Table 1 Summary of survey results and interpretation of soil classification, rock layer from the survey area of Tambon Fai Kwang,

Electrical resistance range (ohm-meter)	Color range (Color scale)	Depth range (meters) found in soil-rock types	Soil layer/rock layer/ rock layer providing shallow water.
Values from 422 and above		1.00 - 15.00	laterite
178 – 422		15.00 - 30.00	sand mixed with clay / rubble / laterite
Value less than 178		30.00 - 100.00	shallow gravel sand deep gravel sediment

Social return on investment (SROI) of shallow ground water recharge system through the concrete circle in pond to community

Table 2 Economic and social impact utilization of shallow ground water recharge system through the concrete circle in pond to Fai Kwang community.

Year	2021 ($)	2022 ($)	2023 ($)	2024 ($)	2025 ($)	Total ($)
1.Return						
1.1 Reduce the cost of buying water for community use per year (purchasing water 18.18 $ per week per household per 4 months)	29,091	29,091	29,091	29,091	29,091	145,455
1.2 Village water sales (The selling price of village tap water is not more than 3.03 $ per month)	3,636	3,636	3,636	3,636	3,636	18,182
1.3 Reduce municipal expenses in helping to buy water for agriculture (municipal projects)	303	303	303	303	303	1,515
1.4 Reduce the cost of dermatology treatment of people in the community (time cost, medication cost, travel cost)	1,212	1,212	1,212	1,212	1,212	6,061
total return	34,242	34,242	34,242	34,242	34,242.	171,212
2. Cost						
2.1 investment cost						
- Budget costs from research projects	7,273					7,273
Total investment expenses						
2.2 operating expenses						

Year	2021 ($)	2022 ($)	2023 ($)	2024 ($)	2025 ($)	Total ($)
- Village water supply management fee (454.54 $)	5,455	5,455	5,455	5,455	5,455	27,273
- Cost of water tap production per month	727	727	727	727	727	3,636
Total cost	13,455	6,182	6,182	6,182	6,182	38,182
NPV (Net Present Value)	114,561.33					
IRR (Internal Rate of Return)	59.23%					

Implementation of the groundwater recharge system with filter and pump water to solve the problem of surface water quality for water supply in the village of Siwilai, Fai Kwang Subdistrict, Phayao Province, which allows the people in the area to use water for 200 households, yielding of SROI of 59.23 % (Table 2) reduction of water purchase and medical expenses from water quality impacts as groundwater has several major economic benefits including promoting human economic activity and generating economic development in rural areas.[12]. The study results have led to the creation of water management policies and the application of data and innovation for drought solutions. Measures and requirements for the use of public water sources for consumption revenue collection for the maintenance of the village's water supply system

This study illustrates that combining remote sensing products with ground-based data to predict spatiotemporal groundwater recharge can potentially be useful for both local and regional water availability evaluations and long-term water resource planning. The utilization of remotely sensed data as given here provides a means for establishing a basin's mesoscale water balance by integrating and analyzing observed data. Both surface and subsurface movement and storage of water are dependent on precipitation, temperature fluctuations, vegetation type and distribution, anthropogenic land and water utilization, as well as topographic, lithological, and soil characteristics[13]–[15].

A global-scale dataset of direct natural groundwater recharge rates: a review of variables, processes and relationships. Groundwater recharge predictions in contrasted climate: the effect of model complexity and calibration period on recharge rates. Predicting groundwater recharge for varying land cover and climate conditions-a global meta-study. Spatial representativeness of soil moisture using in situ, remote sensing, and land reanalysis data. An evapotranspiration model driven by remote sensing data for assessing groundwater resource in karst watershed. Using width-based rating curves from spatially discontinuous satellite imagery to monitor river discharge. Hydrologic model predictability improves with spatially explicit calibration using remotely sensed evapotranspiration and biophysical parameters. Measurement and estimation of actual evapotranspiration in the field predict groundwater recharge for varying land cover and climate conditions-a global meta-study. Spatial representativeness of soil moisture using in situ, remote sensing, and land reanalysis data [16]

We observed a cross section of a thick laterite and sand mixed with clay in soil layer we used transiting in and out of the permanent soil layer from the dock area. The portions of this lens that we could see varied in thickness from tens of cen timeters to more than a few meters thick. Zones of outstanding groundwater potential are observed for basaltic layers overlying lateritized crystalline rocks, flat topography with dense lineaments and structurally controlled drainage channels with valley fill deposits. The study made on hard-rock areas comprising of rocks of Archean age and Chrackonite using Resourcesat data and integrating the derived thematic maps in raster-based GIS showed that the fracture valleys, valley fills, pediment and denudational slopes are promising zones of good groundwater potential in Western Ghats in Kerala, India. The relationship between the vegetation growth and the depth to the water table in the Yinchuan Plain, China, was investigated by combining remote sensing with groundwater data and it was found that the best vegetation growth occurred when the depth to groundwater is around 3.5 m. A study in granitic terrain using RS and GIS carried out by Ratnakar et al (2008) showed that the groundwater potential of deeper aquifers is determined by lineaments such as faults and joints and that of shallow aquifers by geomorphologic features [17].

CONCLUSIONS

We evaluate the regional variance in the usage of managed aquifer recharge, groundwater conservation, economic returns, and the social cost of a managed aquifer recharge subsidy, taking into consideration the dynamics of crop choice and groundwater flows. Our findings address a vacuum in the literature examining the feasibility of controlled aquifer recharge for agricultural settings by taking into consideration not only hydrology, but also agronomic and economic circumstances at the landscape level. We explore not only which hydrologic and economic elements have an impact on conservation and economic objectives but also the extent to which these factors contribute to the achievement of a target. Our modeling technique is also the first to analyze where a subsidy for managed aquifer recharge would be cost-effective for society by examining the social cost of a subsidy for managed aquifer recharge. The ideal quantity of controlled aquifer recharge is greatest in sites with low natural recharge, high net returns to rice and dryland soybeans, and low net returns to corn and soybeans requiring less irrigation. Utilizing controlled aquifer recharge as a supplement with a dryland crop but as a substitute with maize and soybeans to optimize earnings is a valuable discovery regarding how agricultural producers may integrate crop mix selections with water management.

Households were given the option of either one of two aquifer water recharging systems. The residents of the community were given the option to choose the solution that was most suited for their households. The following were the two choices: The first choice is a water tank on the roof. Rainwater collection is possible with this design choice thanks to the slope and shape of the roof of the house. The rainwater is then channeled into a closed recharge pit after some basic filtration, consisting of layers of large stones, small stones, sand, and charcoal. The recharge pit can be located adjacent to the dug well (if it is located close to the home) or it can be located close to the household (if the dug well is not available or is situated too far from the property). At a minimum distance of 15 meters (50 feet), it is advised that recharge pits be kept separate from family latrines. Option Two: Agricultural or unused dug wells Wells that are dug specifically for the sake of agriculture are known as agro-wells. In most cases, they have a modest depth and a wide circumference. The beneficiaries of an agro-well project stated that they considered recharging the aquifers a good long-term investment for the community. This was disclosed in light of the fact that the objective of an agro-well is to collect runoff and stormwater during the wet season for agricultural usage.

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Abbreviations

VES	Vertical Electrical Sounding
PVB	Price to Book Value Ratio
SROI	Social return on investment

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