Enhancing and Restoring Water Systems in Angkor World Heritage Site and Siem Reap City

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Sustainability Science Framework

- Sustainability Science is defined as an emerging field of problem driven, interdisciplinary scholarship that seeks to facilitate interventions that foster shared prosperity and reduced poverty while protecting the environment.

- UNESCO MAB has defined Sustainability Science as an integrated, problem-solving approach that draws on the full range of scientific, traditional and indigenous knowledge in a trans-disciplinary way to identify, understand and address present and future economic, environmental, ethical and societal challenges related to sustainable development (UNESCO MAB, 2015).
1. Co-realization of a common problem

2. Co-envisioning futures

3. Co-shaping into envisioned future society

4. Co-implementation

5. Monitoring and evaluation

Advanced stakeholder involvement and social learning
Background

- The demonstration project “Restoring and Enhancing Angkor World Heritage Site and Siem Reap City Water Systems” is linked with Sustainability of Natural Heritage and Biosphere Reserve connected with Social System and focuses on both strengthening policy, legal and institutional frameworks through collaborative linkages, learning alliances and targeted interventions for capacity building at pilot area, national and regional levels as well as intervening at community level through sustainability building based on urban/rural water management.
Objective

- The key objective of this pilot project is to help restore and preserve Angkor World Heritage Site’s water management system by strategic planning of surface and groundwater systems of Siem Reap and their interactions with ecosystems of Tonle Sap Biosphere Reserve using Sustainability Science approach.
Project Area
Project Area

- Siem Reap is considered as the biggest tourist industry in Cambodia.

- Every year 2.5 to 3 million tourists come to visit Angkor World Heritage Site, where is a place of outstanding heritage value for Cambodian people and for all humanity.

- It was declared as UNESCO World Heritage Site in 1992.

- Now Angkor is rank number one in the world tourist destination.
Research Method

- Literature reviews
- Data collection
- Data analyzing
- Data processing

Define problem

Integrated strategy
- Interview villagers
- Water issue awareness campaign
- Define indicator
- Stakeholder workshop

Implementation plan

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Problem Analysis

- Water balance analysis is a processing to estimate water excess and deficiency compared water demand and supply capacity in the target year.

- Depending on the results of the water balance analysis, water resources development plans can establish to tackle the water shortage issues.

\[ P = Q + E + \Delta S \]

Where,
- \( P \) = Precipitation (mm)
- \( Q \) = Runoff (CMS)
- \( E \) = Evapotranspiration (mm)
- \( \Delta S \) = Change in storage (m³)
# Water Balance Analysis for Siem Reap

<table>
<thead>
<tr>
<th>Water balance</th>
<th>Unit</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water demand</td>
<td>Million m³</td>
<td>326.10</td>
</tr>
<tr>
<td>-Domestic and industrial (including tourist sector)</td>
<td></td>
<td>58.00</td>
</tr>
<tr>
<td>-Agriculture</td>
<td></td>
<td>268.10</td>
</tr>
<tr>
<td>Water supply</td>
<td>Million m³</td>
<td>96.60</td>
</tr>
<tr>
<td>-Groundwater</td>
<td></td>
<td>2.40</td>
</tr>
<tr>
<td>-Surface water</td>
<td></td>
<td>94.20</td>
</tr>
<tr>
<td>Water deficit</td>
<td>Million m³</td>
<td>229.50</td>
</tr>
</tbody>
</table>

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Water Balance Analysis of Siem Reap

- Surface water is not enough to supply water in Siem Reap.
- The total population of Siem Reap is 1.05 million and 21% of the total population live in urban area, 79% live in rural area.
- Every year about 2.5 to 3 million of tourists come to Siem Reap City so domestic water demand in urban is higher than in rural area.
- The number of tourists seem to increase 25% every year.
- The demand of water consumption is also increase every year.
Groundwater Modeling Result Analysis

The preparatory study on the Siem Reap water supply expansion project (JICA, 2011)
Groundwater modeling was conducted by NJS Consultant and Kogyo Co., Ltd by using ModFlow.

The model was conducted to find proper way of expanding water supply in Siem Reap and analysis the effects of land subsidence and water level drawdown under Angkor Wat temple, near Angkor Wat temple, Angkor Thom and West Baray.

Groundwater level drawdown cause land subsidence and can impact to stability of temples in Angkor World Heritage Site.
The simulations was conducted in 7 specific scenarios as below:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Scenario Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>To keep natural condition without any groundwater use. (For model calibration)</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>To continue use groundwater as only source for water supply. Withdrawal volume = 22,176 m³/day</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>To expand more groundwater use as only source for water supply. Withdrawal volume = 86,000 m³/day</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>To use irrigation canal water from West Baray reservoir for water supply and diminish a part of groundwater development volume (withdraw volume including Siem Reap Water Supply Authority production wells: 52,000 m³/day – 69,000 m³/day)</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>To lessen the impact to Bakong ruins, new production wells are not planned in Eastern bank area of the Siem Reap River. Withdrawal volume = 39,000 m³/day</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>To use surface water as water sources for water supply. Pumping by existing wells excluding SRWSA production wells are halted. Consider Tonle Sap Lake water is used. Withdrawal = 9,000 m³/day</td>
</tr>
</tbody>
</table>
### Summary of water level drawdown result

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Near Angkor Wat</th>
<th>Under Angkor Wat</th>
<th>Under Angkor Thom</th>
<th>Near West Baray</th>
<th>Under West Baray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 2</td>
<td>0.73</td>
<td>0.59</td>
<td>0.57</td>
<td>1.34</td>
<td>1.17</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>0.70</td>
<td>0.65</td>
<td>0.74</td>
<td>3.31</td>
<td>2.12</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>0.41</td>
<td>0.38</td>
<td>0.49</td>
<td>2.31</td>
<td>1.62</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>0.51</td>
<td>0.47</td>
<td>0.60</td>
<td>2.83</td>
<td>1.90</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>0.45</td>
<td>0.38</td>
<td>0.49</td>
<td>1.71</td>
<td>1.34</td>
</tr>
<tr>
<td>Scenario 7</td>
<td>0.13</td>
<td><strong>0.12</strong></td>
<td>0.23</td>
<td>1.16</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Source: JICA, 2011
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Near Angkor Wat</th>
<th>Under Angkor Wat</th>
<th>Under Angkor Thom</th>
<th>Near West Baray</th>
<th>Under West Baray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 2</td>
<td>7.02</td>
<td>5.67</td>
<td>5.48</td>
<td>5.84</td>
<td>5.10</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>6.73</td>
<td>6.25</td>
<td>7.12</td>
<td>14.43</td>
<td>9.24</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>3.94</td>
<td>3.65</td>
<td>4.71</td>
<td>10.07</td>
<td>7.06</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>4.90</td>
<td>4.52</td>
<td>5.77</td>
<td>12.34</td>
<td>8.28</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>4.33</td>
<td>3.65</td>
<td>4.71</td>
<td>7.46</td>
<td>5.84</td>
</tr>
<tr>
<td>Scenario 7</td>
<td>1.25</td>
<td>1.15</td>
<td>2.21</td>
<td>5.06</td>
<td>4.19</td>
</tr>
</tbody>
</table>

Source: JICA, 2011
Groundwater Modeling Result Analysis

- The simulation results revealed that potential drawdown of groundwater level and land subsidence to Angkor World Heritage Site would occur in all scenarios in a dry year of 50 return period.
- Especially, Scenario 3 which used groundwater as the only source for water supply resulted in the largest land subsidence and the highest risk.
- Subsequently, Scenario 2 which continues groundwater use by present amount had secondary higher risk.
- The Scenario 7 has the smallest effect to the heritage site. However, the effect is not zero.
- The effect on Angkor Wat is 1.15 mm. It is nearly unimaginable to cause inspectable uneven settlement by this amount of land subsidence.
- On the other hand, the groundwater drawdown is not a suddenly occurring event, but a gradually changing process.
Linked Between Siem Reap River and Tonle Sap Lake
- The source of water in Siem Reap Basin is from Kulen Mountain, located upstream of the basin.
- So the water flow from Kulen Mountain through Siem Reap River and run directly into Tonle Sap Lake.
- Therefore, Siem Reap River and Tonle Sap Lake have interactions with the same ecosystem.
- Any changes with Siem Reap River will effects to Tonle Sap Lake as well.
- Deforestation in Kulen Mountain give much concern to changes of hydrologic system of Siem Reap River.
- Because land use change effect to rainfall pattern and impact to flow volume.
- The changes of flow volume, trapping of sediments and nutrients in reservoirs, bank and cause erosion.
- The declined of water level also impact to fish migration pattern and negatively influences the amount of fish that could catch, too.
Image analyses based on LANDSAT, SPOT undertaken by APSARA and HIST, 2015
- Kulen Mountain is the birthplace of Khmer empire.
- Through Radar image has revealed that 35% of the area is still under forest.
- There is a South-north gradient in increasing deforestation.
- Rates of deforestation were at least 1.5 times higher during the period 2000 – 2014 in comparison to that of 1989 – 2000.
Photos of water condition in Siem Reap River and Tonle Sap Lake
Water pollution in Siem Reap River

- Water pollution is another concern linked to Tonle Sap Lake.
- Tourist industry boom in Siem Reap City shows many hotels, resorts, restaurants and tourist facilities.
- There are many garbage dumps and wastewater directly discharged into the river.
- Even though there is a wastewater treatment plant, many garbage is still dumped in the River.
- The river water is very dark in dry season and some places come with bad smells.
- It affects tourists as well.
Field Visit
Field Visit
- The purpose of field visit is to meet rural communities in Siem Reap in order to find out problem related to water they have and to know what is their vision for future in solving the problem.
- Ten villages around Angkor World Heritage Site were chosen to visit and the interviews.
- 100% from the interview said they use groundwater as domestic water supply.
- 20% face problem with water quality.
- They only do agriculture one time per year depend on raining.
- They wish to have clean water for a living.
- They want to use tap water like resident in Siem Reap City.
Water Awareness Campaign
- Water awareness campaign was conducted to raise awareness on the significance of water and its impact in the communities in Siem Reap society, promoting its proper and sustainable management and conservation.
The objectives of this campaign are:

- To learn and reflect about the importance of water in each community from different perspectives: social, environmental, financial and cultural.
- To value self-experiences as a source of knowledge.
- To enhance dialogue, breaking age and social pyramids through the interaction with key agents in community.
- To share knowledge with other communities to widen the perspective showing the diversity of realities linked to water in Siem Reap.
- To find out new social norms and attitudes towards water use, becoming behavioral change makers in the communities.
I was seen that the participants became better spokespersons on the topic of water in their environments by training and improving their communication skills.

- They could learn scientific information related to the effects of excessive groundwater pumping in Siem Reap City and Angkor World Heritage Site, water pollution and the periodic flooding and degraded ecosystems of Tonle Sap Lake.

- And they could mix this information with their personal experiences, enriching it with the knowledge provided by the key agents of their communities.
Results

- In this study there were three main problems related to water:

1. **Over-exploitation of groundwater** link to stability of temples in Angkor World Heritage Site.

2. **Deforestation** lead to change flow pattern in Siem Reap River link to decrease fish productivity.

3. **Water pollution** by directly dumping garbage near river and wastewater discharge link to health problems of people living in Tonle Sap and fish productivity.
Conclusion and Recommendation

- Groundwater is very important source of water for domestic water supply in Siem Reap.
- However, over-exploitation of groundwater can cause land subsidence. It can directly concern to the stability of Angkor World Heritage Site.
- Groundwater using plan or policy should be made to control groundwater using amount that can harm to the ancient temple in the future.
- Groundwater pumping information is very important for estimate the volume of groundwater use.
- Therefore, groundwater data should observe accurately.
- Groundwater monitoring system should be conducted to control groundwater use in Siem Reap City.
Conclusion and Recommendation

- It was seen that deforestation is a problem affecting directly to the change of direct discharge which impacts to fish migration pattern.

- Fish production is very important to millions people living in Tonle Sap Lake.

- The change of flow regime directly impact to fish productivity.

- Any plan should take into account to protect forest upstream of Siem Reap basin. The local government should make strong action to protect forest and illegal deforestation in those area.
Conclusion and Recommendation

- Water pollution is another problem in this study area.
- The polluted water in Siem Reap River flow directly into Tonle Sap Lake.
- Garbage dumping near source of water or throwing directly into the river should prohibited.
- Environmental impact of water pollution should be aware by the residences.
- Any action plan should do to make sure people will not throwing garbage or waste into the river.
- The stakeholder workshop is planning to do at the end of this month in Siem Reap with local government, villager, NGOs to share opinion and real problems in order to find proper solution and define indicator for solving those problems.
Thank you!