Reducing erosion and eutrophication through soil and water conservation practices in upper Lake Rawapening

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Abstract. Agriculture has been one of erosion and eutrophication sources in Lake Rawapening. Former research found massive fertilizer use on agricultural area in Rawapening catchment. Vegetable farming contributed the biggest percentage of Nitrogen and Phosphorus input that are 953.7 and 118 tons/year respectively. These were followed by irrigated paddy field with 845.8-ton Nitrogen/year and 208-ton Phosphorus/year. This lake has nine sub-watersheds: Parat, Sraten, Panjang, Kedungringin, Rengas, Legi, Galeh, Ringin, and Torong in which Panjang has the highest pollutant contribution to the lake. Since Panjang is the most significant sub-watershed and has extensive vegetable farming, therefore research to identify applicable practices in reducing erosion and eutrophication was undertaken in the area. Field surveys and interviews with landowners were employed. Field surveys included observing riparian, measuring catchment size, slopes, documenting existing land uses and ownerships. Interviews involved 52 landowners in Dusun Bendo and Ngonto, Desa Candi, Kecamatan Bandungan, Kabupaten Semarang. Based on existing practices and potential techniques, we propose soil and water conservation practices variables. They can be grouped into three: runoff farming, mini bridges, and terrace strengthening. Runoff farming consists of three techniques: individual/group infiltrating wells, on-site sediment traps, and drainage enhancement. Majority landowners choose infiltrating well for its easiness on obtaining materials and constructing. On-site sediment traps are rejected because of inundation concern, but farmers with very small landownership consider this choice as long as the traps has drainage system. Almost all farming land have mini bridges and terraces. They acknowledge that terraces were inherited from their predecessors.

1. Introduction
Eutrophication has become a worldwide environmental problem in recent years [1]. In Indonesia, most of major lakes are facing environmental problems such as eutrophication, sedimentation, and decline surface area [2]. Lake Rawapening in Semarang Regency is one of the priority lakes that have ecological, hydrological, and economic functions, but experiencing eutrophication. Lake Rawapening is a habitat for flora and fauna biodiversity, water sources for agricultural irrigation (Semarang, Demak, and Grobogan regencies), tidal rice fields, water supply for drinking water companies, fishery, water tourism, energy sources for hydroelectric power (PLTA Jelok and Timo), water hyacinth (Eichhornia crassipes) craft, water hyacinth-peat mining as a raw material for organic fertilizers, maintain water management, and flood control [3]. However, Lake Rawapening also has several unresolved problems, namely the explosion of the water hyacinth population, lake sedimentation, and eutrophication.
In addition, there has been a decrease in lake water quality, with a total Nitrogen (N) of 28,303 kg/day (eutrophic status), and Phosphorus (P) of 5,244 kg/day [4-5]. Sedimentation in Lake Rawapening comes from the deposition of soil material transported by river currents from the catchment area, and the remains of dead aquatic plants [6-8]. The amount of sedimentation in Lake Rawapening is estimated at 778.93 tons/year, while the sedimentation rate in 2015 is 1.77 mm/ha/year [5]. The explosion of water hyacinth population and sedimentation reduces not only the lake's water discharge but also its capacity and function as a flood controller [5, 9].

In general, lakes receive water input from the catchment area around the lake. Lake waters tend to receive dissolved materials that are transported along with the incoming water. Therefore, the concentration of substances in the lake is the resultant of substances originating from the incoming water flow [10]. Based on nutrient content, lakes are classified into 3 types, namely: (1) oligotrophic lakes, (2) mesotrophic lakes and (3) eutrophic lakes. Eutrophic lakes are lakes that have high nutrient levels, have shallow waters, algal bloom, higher plankton density, frequent algal blooms with generally low levels of sunlight penetration [11]. Meanwhile, oligotrophic lakes are lakes with low nutrient levels, usually having deep waters. The deeper the lake the less fertile, the littoral plants are sparse and the plankton density is low, but the number of species is high. Mesotrophic lakes are lakes with moderate nutrient levels, also a transition between the two characteristics of eutrophic and oligotrophic lakes [12].

Biological processes tend to dominate the oxygen regime of productive waters [13]. Increased eutrophication will reduce dissolved oxygen. Nutrients can be increased through erosion and through feeding the fish (e.g., on floating nets). This accelerates the disruption of the natural balance of the waters. The richer the nutrients in the water body, the aquatic plants will be more fertile, dense and cover the surface of the lake waters. The waters of Lake Rawapening will be increasingly turbid due to the density of these aquatic plants, which ultimately makes it difficult for sunlight to penetrate the lake waters. In the end, the decay of aquatic plants will increase and this will escalate sedimentation which is definitely the cause of silting of the water body.

The process of sedimentation and eutrophication in Lake Rawapening leads to a decrease in water quality and quantity, thereby reducing the economic and ecological benefits of Rawapening. Saving Lake Rawapening's activities carried out in the lake body will be fruitless if the supply of sediment and nutrients from the inlet rivers is not reduced. Therefore, the activities of saving Lake Rawapening in the lake body and upstream areas must be synergistic and sustainable. Raharjo et al. [14] suggested that collective actions are needed to solve Rawapening's problems. For effective actions, social and economy incentives [15], incentives from government [16], and the enforcement of norms and laws [17] are also important.

Agricultural activities, especially in the upstream catchment area of Lake Rawapening, are a major contributor to nitrogen and phosphorus supplies. Murtono and Wuryanta [18], Nugroho [19], and Hidayati et al. [20] conclude that of the nine sub-watersheds: Parat, Sraten, Panjang, Kedungringin, Rengas, Legi, Galeh, Ringin, and Torong in which Panjang has the highest pollutant contribution to the lake. Since vegetable farming and Panjang are the most significant land use and sub-watershed, it is necessary to make appropriate, fast and measurable efforts to reduce the nutrients inputs, especially nitrogen and phosphorus into the lake so that efforts to save Lake Rawapening can be realized. Based on the description above, this research is to identify applicable practices in reducing erosion and eutrophication that can be undertaken in the area.

2. Method
The research location is in the upstream catchment area of Lake Rawapening. The location determination was carried out by delineating land use map in 2017 which contributed the most to eutrophication, carried out using the INVEST simulation method [19].

Field surveys and interviews with landowners were employed. Field surveys included observing riparian, measuring catchment size, slopes, documenting existing land uses and ownership. Interviews were conducted to determine the community's willingness to apply simple soil and water conservation
technology and the locations that allow it to be applied. Soil and water conservation practices using physical structures were offered as the community rejected planting riparian \[21\] and mixed their crops with trees \[22\]. The structures offered were terraces construction, infiltration wells, rorak/silt pit/dead-end canal/ditch, and drainages improvement. Interviews involved 52 landowners in Dusun Bendo and Ngonto, Desa Candi, Kecamatan Bandungan, Kabupaten Semarang.

3. Results and discussion

3.1. The existing condition of upper Panjang River

Panjang River is one source giving rise to eutrophication and sedimentation to Lake Rawapening. Murtiono and Wuryanta \[18\] examined that Panjang River in which land use systems are dominated by vegetable agriculture contributed the most to Rawapening pollution. Based on the results of the INVEST simulation in the following year, vegetable land in Candi Village and other villages in the upper Panjang River is the main contribution compared to other land uses \[19\]. These findings can be the basic justification that appropriate efforts are needed to reduce the nutrients that enter Lake Rawapening.

Field surveys and observations show that riparian in the upper area has been used intensively for both vegetable farming and settlement. This corresponds to the previous study in Rawapening catchment realizing that farmland and building areas including settlement increased by 1.5 times and twice respectively from 2001 to 2011 periods \[23\]. Vegetables cultivated in Candi Village consist of chili, leek, celery, mustard greens and spinach with roses planted on the edge of the terrace. Field observations also found that the riverbed was still dominated by rocks and the riverbanks were also heavily reinforced with arranged stones, calliandra and other grasses (Figure 1).

![Figure 1. A riverbed and a riverbank in vegetable farming land in Candi Village.](image_url)

Field observations show that the agricultural land in Candi Village has a slope of 28-35% with a slope length of 10-40 m. Apriliana \[23\] analysed land uses changes in Rawapening from 1991 to 2011. The results showed that since then agricultural land were extended by cultivating land with 25-40% slope even steeper than 40%. Within a terrace, the land is divided into several raised beds depending terrace length. The bed width (cultivated land) ranging from 50-100 cm with a drainage of 30-50 cm width. Distances between the terraces are 30-100 cm and terraces heights are 50-160 cm. With these slope values, without land conservations, vegetable farming land will experience degradation \[24\].

Soil and water conservation in the form of terraces and drainages have been carried out in all vegetable fields. In the dry season, water flowing in the river was clear; however, surface runoff and its materials can still be seen through the muddy water in the river when it rains. A couple of the
identified causes is the presence of unprotected riverbanks in some part of the river and sediment from arable land that is carried away by surface runoff when it rains. The most severe eroded bank by bigger current was the bank toe whereas almost all the bank head was covered by grasses. On the farmland, the sediment mainly comes from damaged terraces and tillage that prone to erosion (Figure 2).

3.2. Soil and water conservation structures for reducing sedimentation and eutrophication
The reduction of eutrophication and sedimentation rate should be carried out simultaneously because the constituent materials of both are mostly carried by rainwater flow. Discussions with land owners described that vegetable agroforestry was once offered by extension workers but rejected by land owners. This finding is in line with a result from Castle et al. [25] who studied that income from agroforestry is relatively small therefore it is unfavourable for intensive farming. In this study site, the farmers object the choice because tree crops in the agroforestry system interfere with agricultural crop production. Farmers prefer conservation techniques that do not have a major impact on their agricultural production which will directly affect household income. This is supported by the findings of Kadigi et al. [26], Madsen [27], and Ngoma et al. [28].

Conservation activities found and applied by land-owning farmers include artificial ground cover (plastic mulch) (Figure 3), maintenance of terrace edges by making small bridges from one land to another that can reduce damage to the edges (Figure 4), dead-end canals and strengthening of terraces. In addition, plastic mulches can increase income, reduce pests and diseases attacks, and decrease soil erosion [29]. An important note regarding plastic mulch’s is it will result in plastic pollution like in China [30-32].

Figure 2. Soil management prone to erosion.

Figure 3. Artificial mulch from plastic able to protect soil from rainwater energy.
Figure 4. Wooden mini bridge.

Alternative simple soil and water conservation structures to reduce erosion, sedimentation and eutrophication that can be applied in the upstream of the Panjang River include: infiltration wells, infiltration wells with floating potted plants, dead-end ditches/canals/rorak, repair of drainage channels, repair and strengthening of terraces, mini bridges from wood/bamboo, and strengthening of riverbanks. Soil and water conservation structures that potentially reduce not only erosion and sedimentation but also eutrophication include infiltration wells, infiltration wells with floating potted plants, and rorak. The structures that can be effective in overcoming both sedimentation and erosion include repair of drainage channels, strengthening of terraces, mini bridges (Figure 4), and strengthening of riverbanks.

Based on existing practices and potential techniques, we propose soil and water conservation practices. They can be grouped into three: runoff farming, mini bridges, and terrace strengthening. Runoff farming consists of three techniques: individual/group infiltrating wells, on-site sediment trap/rorak, and drainage enhancement. Other efforts made include:

3.2.1. Rainwater harvesting from agricultural land (Runoff Farming). Rainwater harvesting from agricultural land aims to reduce erosion and supply water to waterways, rivers and other water bodies. Some of the techniques used include the following:

Figure 5. An example of walled infiltration well (BPUSDA Taru Bodri Kuto, 2018).

3.2.1.1. Infiltration wells. The collecting of surface runoff can also be carried out by making infiltration wells (Figure 5) on the land provided by the owner. Sizes and shapes may vary depending
on the preferences of the land owner. This practice can refer to rainwater harvesting in agricultural land in other countries such as China [33], Pakistan [34], and Iran [35] and almost all of their practices also increased crop productions. Various implementation examples of rainwater harvesting were also provided by FAO [36]. If favourable, farmers may plant additional/ornamental crops on the well surface. Plants harvested by farmers can also be added to this infiltration well by means of hanging pots that are placed at least parallel to or lower than the surrounding soil. Plants that are above the well function as absorbing nutrients contained in the water so that it is expected to reduce the nutrient content [37].

Previous researches involved only rainwater harvesting from rooftops also found that infiltration wells can reduce surface runoff. A well sizing one m in diameter and two m in height reduced surface runoff by 48.88%/day during rainy season [38]. Saleh [39] guaranteed that if each house construct an infiltration wells with size varieties (diameter 0.45-0.75 m with 1.6-2.9 m depth), all surface runoff and rainfall can be accommodated by the wells. The specifications of those type of wells can be found in existing guidelines such as PERDIRJEN PDASHL No. 6 of 2017 on Soil and Water Conservation Structures [40] and SNI 8456 of 2017 on Rainwater Infiltration Wells and Ditches [41].

3.2.1.2. Rorak construction. The rorak found is only one of hundreds of fields that have terraced (Figure 6). This rorak, if in large quantities, in addition to accommodating eroded soil, its functions will vary, including reducing runoff, incorporating water into the soil/groundwater, thereby delaying the soil to dry and increasing groundwater reserves [40]. Roraks together with infiltration channels controlled surface runoff, stored rainwater, and hold soil water longer [42]. In Kabupaten Lebak, Banten Province, Sihombing and Prastowo [43] recommended terraces and rorak to overcome flood and prevented erosion in the regency. A current research from Santos and Kusuma [44] proved that roraks combined with mulch reduced surface runoff and erosion and increased maize production.

![Figure 6. Elongate rorak.](image)

3.2.1.3. Repair of drainages (SPA) and sediment filters. Waterways from the cultivated land firstly go to the cultivated land below or directly connect to the main water channel which then drains the water into the river. The water that flows here often carries associated material such as sediment or even fertilizer. These can be retained by adding filters (from dried grasses or other permeable and more durable materials). Technical guideline for drainage construction can refer to PERDIRJEN PDASHL No. 6 of 2017 [40].
3.2.2. Terrace strengthening. Terraces stabilizations both vegetative and other construction are carried out by some farmers, while others are still in the existing forms. Stabilization from stones, rocks, or grass is needed if the vertical sides (steep risers) are more than 1 m and soil types are also unstable [45]. Efforts to repair the damaged terraces have not been seen, however since 2019, there has been program from central and local government to overcome erosion and sedimentation in Rawapening catchment [46-47]. This can be incentives as suggested by Bartley et al. [48].

3.3. Public perception of alternative soil and water conservation structures

The results of the survey and discussions with farmers who own land along the Panjang River in Dusun Kalibendo and Ngonto, Desa Candi, Kecamatan Bandungan, Kabupaten Semarang explain the community's perception on constructing various soil and water conservation structures in their fields. Community responses to these practices are quite diverse and depend on socio-economic conditions and the location of their land. The study from Schattman et al. [49] showed that the motivation of conservation behaviour improves with non-monetary rewards.

3.3.1. Infiltration wells. A total of 42 respondents (80.8%) agreed to make infiltration wells in their garden. Infiltration wells are seen as able to help store groundwater, to accommodate erosion, and to reduce topsoil loss in fields. Making infiltration wells is also easy, the materials are easy to obtain, and are seen as not disturbing the plants. Meanwhile, those who objected reasoned that their gardens were too small for infiltration well/s to be built, and had already built canals in their gardens. To maximize their canals functions, additional rorak may be added to the canals as implemented by Surdianto, et al. [42] in starfruit plantations in Depok.

3.3.2. Rorak/dead-end canals. The community objected roraks because there was inundated water and disturbed the growth of vegetable plants so that the plants would rot. In principle, in vegetable farming, water needs to flow so that the soil consistently dry. This waterlogging potential has been warning by Balittananah [50] especially for areas with high clay content soil and high rainfall. Rorak need to be combined with other rainwater harvesting practices [50] such as drainage canals [42]. In Queensland, Australia, good drainage in particular for horticulture farming is very important as some crops are intolerant of waterlogging [45].

3.3.3. Mini bridge. The mini bridge is intended to reduce erosion or soil loss on the river bank or terrace edges from trampling especially when people want to cross the river/land. Trampling increased soil loss through breaking soil surface layers [51]. Trampling also resulted in reducing soil permeability and porosity [52]. In principle, the community has a positive view on the bridge existence because it will reduce falling soil, make it easier to cross rivers/land, and be safer from falling/slipping. The construction of a mini bridge requires materials such as bamboo and can be done in a maximum of half a day.

3.3.4. Terrace strengthening. The community has implemented a lot terraces and even constructing them from stones on agricultural land. This knowledge comes from their predecessors to prevent soil loss. Reinforcement of the terrace with stones makes the terrace more stable. In study site, materials needed include stones and labours and the project can be completed within 3-4 days. This is supported by a guideline book from Australia indicating that terraces cost more than other structures especially when the terraces are wider and the steep risers/vertical sides are higher [45]. Moreover, a current constraint of those stone terraces is rats making holes in terraces and collapsing the terraces at any time.

Communities have also developed a system for holding their precious land, which they call kalenen or sukonan. Kalenen or sukonan is water channel with different heights so that the soil will be retained and the flowing water does not carry the soil that is washed away or welud. After it is full or level, the land is taken to be returned to agricultural land. To do this takes about 2 to 3 days. In addition, with
their local knowledge, the community also makes jeglongan or ledokan which is often covered by plastic to collect water (mini ponds) for watering plants during the dry season and mixing pesticide for spraying agricultural crops. Making a mini pond can be done in about 3-4 days.

The majority of landowners choose infiltration wells because of their easiness in obtaining materials and construction. Sudha and Sekar [53] found that expensive investment become farmers consideration to apply conservation practices on their lands. They also believe that the well does not interfere with the vegetables. Only small percentage object to build a well that is those with very small land ownership. Sediment traps on-site were also rejected because of inundation concern, but farmers with very small land ownerships considered this option as long as the traps had a good drainage system. Almost all agricultural land has a terrace. They admit that the terrace is a legacy from its predecessors.

4. Conclusion
Farmers who own land in the upstream catchment area of Lake Rawapening have carried out many soils and water conservation activities to reduce erosion, sedimentation and eutrophication. The conservation activities can be grouped into three, namely runoff farming/agriculture (infiltration wells, roraks, drainages), mini bridges and terrace strengthening. The majority of landowners choose infiltration wells and mini bridges because of their easiness in obtaining materials and construction. They also do not interfere with their vegetable crops. Sediment traps/roraks are less preferred because they create inundated water that interferes with vegetable growth, but farmers with very small land holdings consider this option as long as the trap has a drainage system. Economic considerations determine the choice of land conservation techniques. Community recognizes the terraces as a legacy from their predecessors.

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