Effects of continuous flushing on the sediment removal efficiency in settling basins of small scale irrigation projects; a case study of kiriku-kiende irrigation project, embu county, kenya

Abstract

Reservoir based irrigation schemes present sediment problems of various types. These problems affect the performance of the settling basin in sediment deposition. One of the major problems is the deposition of sediment in the basin and consequent loss of storage capacity. The design of settling basin involves determination of a combination of width, depth and length of the basin for desired removal efficiency of sediment above a given size. The aim of this study was to compare the effect of continuous removal of sediment from a basin to that of periodic removal. A physical model that was sized to resemble the settling basin of Kiriku-Kiende irrigation project was set up in the Civil Engineering laboratory of Jomo Kenyatta University of Agriculture and Technology. The physical processes for this research involved five experiments on sediment settling in different settling time and same inflow rate. The results obtained shows that settling tanks with continuous sediment removal have a higher sediment removal efficiency of 65.5% against 24.4% for those without a flushing component.

Keywords: Efficiency, Flushing, Irrigation, Sediment, Settling basin

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Introduction

Surface irrigation is a widely used farming system for crop production as it requires less skilled labour and involves less operational cost. Surface irrigation systems contributed to about 90% of the world's crop land irrigation promoting furrow irrigation as the main application method.[1] However, poor design and management, non-uniformity of water application, and over-irrigation featured in surface irrigation are responsible for inefficient irrigation, leading to wastage of water, water logging, salinization, and pollution of surface and ground water resources.[2] Irrigated agriculture is under serious risk due to substantial soil losses from highly erodible soils.[3–5] Irrigated agriculture has been faced with challenges such as sediment loading in the river basins, settling tanks and dams.[6] Many factors such as surface and solids loading rates, tank type, solids removal mechanism, inlet design, weir placement and loading rate affect the capacity and performance of a settling tank.[7] The management of sediments in river basins and waterways has been an important issue for water managers throughout the history as from the ancient Egyptians managing sediment on floodplains.[8] Currently, water managers are faced with similar challenges mainly resulting in siltation of water reservoirs, reduced capacity of water transport, annual irrigation acreage reduction and high maintenance cost for an irrigation project.[9,10] Kenya is not exempted from the dangers posed by sedimentation and siltation in her water bodies. According to,[11] a high proportion of sediments generated in the catchment areas is delivered through soil erosion to the rivers and lakes. Effective management of sediments from rivers during irrigation water abstraction by use of settling basins has become increasingly important from an economic and environmental perspective. Many factors such as surface and solids

loading rates, tank type, solids removal mechanism, inlet design, weir placement and loading rate affect the capacity and performance of a settling tank.[7] Sediments in irrigation network causes clogging and blocking of irrigation structures. This contributes to overall low irrigation water delivery to the farms. This study was to examine the effect of continuous sediment flushing versus desilting. This would form a basis for designers of settling basin for consideration of continuous flushing for eventual increase of the overall efficiency of irrigation systems. In Kenya, smallholder irrigation development is one of the key strategies for land use intensification with expected positive effects on rural incomes and poverty alleviation. About 20% (106,600 ha) of the potential irrigable land is already under irrigation where 50% (53,300) of this area is under smallholder irrigation.[12–14] Table 1 presents the land under irrigation in each basin.[10–15]

Principle of sediment particle settling: The suspended solids in water with a specific gravity greater than that of water usually tend to settle down by gravity as soon as the turbulence is retarded by offering storage. If a particle is suspended in water, it initially has two forces acting upon it. These forces are represented by two Equations.[16] Equation 1 represents the force of gravity acting on the particles while the buoyant force is given by Equation 2.

$$F_G = \rho_p g v_p \tag{1}$$

$$F_B = \rho_w g v_p \tag{2}$$

Where:

F_G = Gravitation force (N)

F_B = Buoyant force (N)

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ρ_p = Density of particle (kg/m³)

V_p = Volume of particle (m³)

g = Acceleration due to gravity (m/s²)

If the density of the particle differs from that of the water, a net force is exerted and the particle is accelerated in the direction of the force. This net force given in Equation 3 becomes the driving force.

$$F_{net} = \left(\rho_p - \rho_w \right) g V_p \qquad (3)$$

Where:

F_{net} = Net force (N)

ρ_p = density of particle (kg/m³)

ρ_w = density of water (kg/m³)

V_p = volume of particle (m³)

g = Acceleration due to gravity (m/s²)

Once the motion is initiated, the drag force as given in Equation 4 is created due to viscous friction.

Table 1 Irrigation potential and development by basins

Basin	Total potential for irrigation (hectares)	Developed area (hectares)	Balance
Tana	226,224	64,425	161,799
Athi	91,006	44,898	46,108
L Victoria	297,213	15,094	282,119
K valley	101,753	9,587	92,166
E Ngiro	49,379	7,896	41,483
Total	765,379	141,900	623,675

$$F_d = C_D A_p \rho_w \frac{V_s^2}{2} \qquad (4)$$

Where:

C_D = drag coefficient

A_p = Cross-sectional area of particle perpendicular to the direction of movement (m²)

V_s = Settling velocity of the particle (m/s)

Sediment flushing in a settling basin: A further consideration in the design of a sedimentation basin is the provision of adequate storage for settled sediment to prevent the need for frequent de-silting.[17] This has been the problem in Kiriku-Kiende irrigation project where the silt has to accumulate for some time before being removed. The project abstract water from Kirurumwe river. Kirurumwe River basin is characterized with loose red soil and a steep slope and as such during rainy season there is a lot of soil erosion. This soil is carried into Kirurumwe River which makes the river highly turbid. The volume of accumulated sediment is estimated from regular monitoring of sediment levels with a measuring post and reference against the top water level.[18] As a rule, the recommended frequency of basin de-silting is once every five years, which is generally, triggered when sediment accumulates to half the basin depth. Flushing sediments through a reservoir have been practiced successfully to combat the storage loss for many reservoirs of the world. Worldwide average annual reservoir storage loss due to sedimentation is about 1.0 %.[19–21] Deposited sediments are removed from the basin by use of the flushing system or through excavation (de-silting) if the amount of sediments is small at a pre-determine time.[22] Flushing involves the opening of the settling basin bottom outlets and allowing the accumulated sediment to be re-suspended and flushed out. According to,[23] flushing can be done without allowing the pool level in the basin to drop down significantly (partial drawdown flushing) or full drawdown flushing in which the basin level is allowed to be completely drawn down.[18] Examined the effect of flushing on the settling basin efficiency performance and proposed that the inflow channel up to the basin to be designed to carry more than the discharge requires as continuous flushing uses about 15 to 20% of the channel water. There are three different types of solids in turbid water. These are total solids, total suspended solids and settleable solids. Total solids (TS) are the sum of total suspended solids (TSS) and total dissolved solids (TDS). Total solids is the material left in the evaporation dish after it has been dried for at least one hour or overnight in an oven at 103°C to 105°C and is calculated according to Standard methods[24] as given in Equation 6.

$$\frac{MgTS}{L} = (A - B) \times 1000 \qquad (5)$$

Where:

A = Weight of dried residue plus dish (mg)

B = Weight of dish (mg)

1000 = Conversion of 1000 mL/L

The Total suspended solids (TSS) refer to the non-filterable residue. The TSS standards for effluents are usually set between 12 mg/L and 30 mg.[25] Total suspended solids (TSS) are particles that are larger than 2 microns found in the water column. Anything smaller than 2 microns (average filter size) is considered a dissolved solid. Most suspended solids are made up of inorganic materials, though bacteria and algae can also contribute to the total solids concentration.[26]

These solids include anything drifting or floating in the water, from sediment, silt and sand to plankton and algae.[27] As algae, plants and animals decay, the decomposition process allows small organic particles to break away and enter the water column as suspended solids.[28] Chemical precipitates are also considered as a form of suspended solids according to.[29]

TSS is calculated using Equation 6.

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$$\frac{MgTSS}{L} = \left(C - D\right) \times 1000 \qquad (6)$$

Where:

C = Weight of filter and crucible plus dried residue (mg)

D = Weight of filter and crucible (mg)

1000 = Conversion of 1000 mL/L

A settleable solid is the term applied to the material settling out of suspension within a defined time. It may include floating material.[25] Settleable solids are an important pathway for pollutants found in river sediments. Special measurements are undertaken to determine the relationship between the settling distribution of settleable solids and their pollutant load - organic mass, chemical oxygen demand, heavy metals and organic micro-pollutants.[30]

Materials and methods

Study area and location: The Kiruku-Kiende Irrigation project is located in Gaturi South in Nembure division of Embu West Sub-County in Embu County at coordinates 9949924N, 336052 E and at an average elevation of 1508m above sea level as shown in Figure 1.
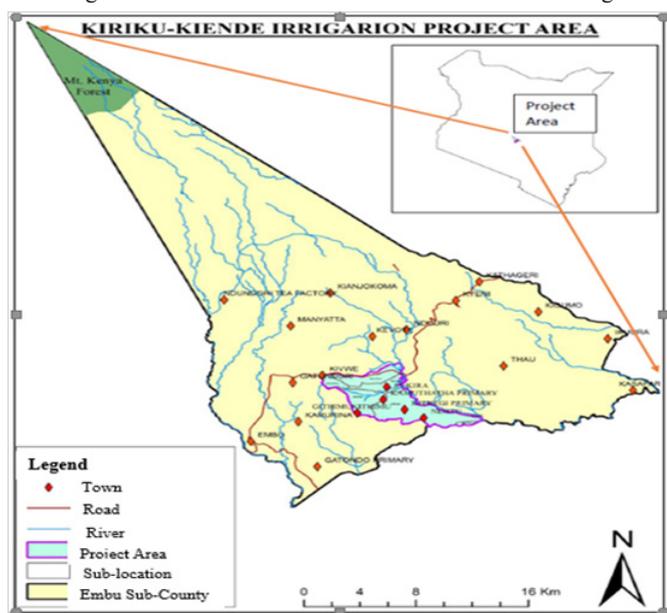

Figure 1 Map of the study area.

The experimental set up: A physical model (Figure 2) of settling basin with a header tank was fabricated and used to run the various experiments (Figure 3). The study using the model was carried out in the Civil Engineering Laboratory at Jomo Kenyatta University of Agriculture and Technology (JKUAT). Using settling velocity for a sand particle formula [24] and a tank sizing ratio of ratio 2:1 for linear measurements, the dimensions of physical model for settling basin were taken as Length of 2m, breadth of 0.5m and a height of 0.4m. The inflow pipe used was of diameter 50mm connected to a header tank at a height of 1.6 m with a measuring flow meter next to the control valve. In this height there was considerable minimum head for water to flow in the settling tank by gravity. The sand particles for preparing turbid water were passed through sieve no.100 with

sieving mesh of 0.20mm in diameter in order to achieve the discrete sand particles for the experiment. Two types of experiments were conducted: The first set of runs pertain to the removal efficiency of the settling basin when there was no flushing, and the next set of runs pertain to the removal efficiency of the settling basin when flushing was introduced. The discharge was measured using a calibrated bend meter positioned in the supply line. Uniform flow of 11.1 l/min in the inlet pipe was established by operating the gate valve. The desired sand concentration of 500g was added to the water in the header tank, stirred and then let into the settling basin. The sediment was allowed to settle for 300minutes after which it was slowly drained using a wash out by opening the control valve mounted at the sub surface of the tank. The settled wet sediments were collected oven dried and the weights recorded. The oven temperature was set at 110⁰c and the sand was dried for 30 minutes, this was to ensure a steady state condition of the sand was reached with about 10-20% of moisture as outlined in BS 1377: part 2: 1990.[31] This procedure was repeated for four different experiments with the same flow rate and weight recorded. On the second experiment, the same flow of 11.1 l/min was set and the same quantity of 500 grams of graded sand added into the header tanks. The flushing outlet pipe was set at 4.8 l/min. The turbid water was let into the basin and after 60 minutes, the outlet (flushing) pipe was opened for 15minutes and then closed. The amount of sediment remaining in the basin was then collected and dried in the oven and the weight recorded in accordance with the procedure of drying earlier described. This was repeated for four other experiments where the flow rate was set at 11.1 l/min and water in the header tank mixed with 500g of graded sand. After settling for 40 minutes the wash out was opened at 4.8 l/min for 15 minutes. The settled sand was then removed and oven dried. Results are presented in Table **2.**

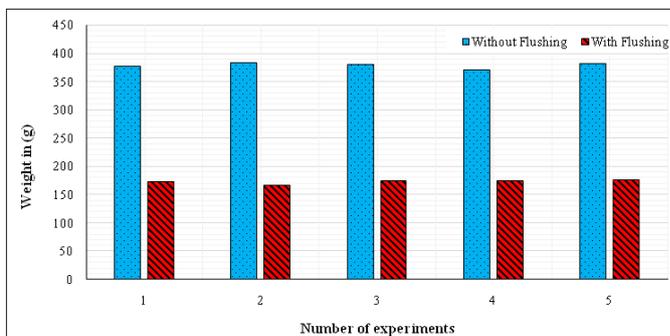
Figure 2 The Experimental physical model.

Figure 3 A comparison of sediment flushing.

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Sediment flushing efficiency of the tank was calculated using Equation 7.[32]

$$\lambda = \frac{S_{out}}{S_{in}} \qquad (7)$$

Where:

λ = the tank sediment flushing efficiency

S_{out} = is the flushed sediment amount out of the tank (gram)

S_{in} = is the sediment inflow into the tank (gram)

Table 2 Weight of settled sediments with and without continuous flushing

	Sediment weight (g)				
	1st Experiment	**2nd Experiment**	**3rd Experiment**	**4th Experiment**	**5th Experiment**
Without Flushing	376.7	382.1	379.8	369.9	380.4
With Flushing	171.8	166.8	174.2	173.7	175.2

Results and discussion

Table 2 shows the results on the sediment flushing in the basin.

The result in Table 2 is presented in a bar graph as shown in Figure 3. By applying Equation 4 on settling velocity of the particle and Equation 7 on sediment flushing efficiency, it was found that the sediment removal from the tank without continuous flushing had an efficiency of 24.44%. While the flushing efficiency for the tank with continuous flushing was calculated to be 65.53%. The results were consistent with the findings of[33] that gave about 53% flushing efficiency of sediment on a research carried at ABC's generating station in Kansas. Sediment removal efficiency in the range of 50-70% is acceptable.[25] The information generated from this study would be important for re-designing of a sound settling basin for Kiriku-Kiende irrigation project.

Conclusion

Settling tanks with continuous sediment removal have higher sediment removal efficiency at 65.5% against 24.4% for those without a flushing component. This shows that water flowing from the settling basin to the conveyance pipe from a settling tank without continuous flushing carries more sediment which eventually reduces the irrigation efficiency of the project and also causes regular maintenance of appurtenances within the system.

Recommendations

Simulation of sediment flushing with more observed data on settling basin for small-scale irrigation projects with the use of baffles in consideration is recommended.

Anknowledgement

None.

Conflict of interest

None.

References

1. Food and Agriculture Organization. Water uses, AQUASTAT. 2013.

2. Damodhara RM, Narendra SR, Rajendra. Sediment transport model for a surface irrigation system. *Applied and Environmental Soil Science.* 2013:1–10.

3. Berg RD, Carter DL . Furrow erosion and sediment losses on irrigated cropland. *Journal of Soil and Water conservation.* 1980;35(6): 267−270.

4. Kemper WD, Trout TJ, Brown MJ, et al. Furrow erosion and water and soil management. TRANSACTIONS of the ASAE. 1985;28(5):1564–1572.

5. Trout TJ. Furrow irrigation erosion and sedimentation: on-field distribution. Transactions of the ASAE. 1996;39(5):1717−1723.

6. Karina FZ, Mwaniki AW. Irrigation Agriculture in Kenya. Think Interactive limited. Nairobi-Kenya.FAO. Coping with a changing climate; consideration for adaption and mitigation in Africa, Rome, Italy; 2011.

7. Singh G, Kumar A. Performance evaluation of desilting basins of small hydropower projects. *ISH Journal of Hydraulic Engineering.* 2016;22(2):135–141.

8. UNESCO. Sediment issues and sediment management in large river basins. *Interim case study synthesis report.* UK; 2011.p.1−82.

9. Yon TH, Lee SO. Hydraulic behavior and Removal efficiency of settling tanks. *Journal of Civil Engineering.* 2000;4(1):53–57.

10. Namu PN, Raude JM, Mutua BM, et al.Prediction of water turbidity using artificial neural networks. A case study of Kiriku-Kiende settling basin, Embu County, Kenya. *American Journal of Water Resources.* 2017;5(3):54−62.

11. Onyando JO, Kisoyan P, Chemelil MC. Estimation of potential soil erosion for River Perkerra catchment in Kenya. *Water Resources Management.* 2005;19(2):133–143.

12. FAO. Unlocking the water potential of agriculture, FAO, Rome, Italy; 2003. p. 1−72.

13. Home PG, Ngugi HN. A comparative evaluation of Irrigation efficiencies for smallholder irrigation schemes in Murang'a South District. *Scientific Conference Proceedings.* 2012.

14. Kangau SN, Home PG, Gathenya JM. Performance and economic evaluation of pumped irrigation system. *Journal of Agriculture, Science and Technology.* 2012;14(2):601–606.

15. Leonard HO, Timothy N . A review paper on large-scale irrigation in Kenya. A case study of maize. Tegemeo Institute of Agricultural policy and Development, Egerton, Kenya; 2016. p. 1−38.

16. Zhiyao S, Tingting W, Fumin X, et al. A simple formula for predicting settling velocity of sediment particles. *Journal of water science and Engineering.* 2008;1(1):37–43.

17. Fornshell G. Settling basin design, Western Regional Aquaculture Center. University of Washington, USA; 2000. p. 1−6.

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18. Raju KG, Kothyari UC, Srivastar S, et al. Sediment Removal Efficiency of settling basins. *Journal of Irrigation and Drainage Engineering.* 1999;125(5):308–314.

19. Yang X. Manual on sediment management and measurement. Secretariat of the World Meteorological Organization, Geneva, Switzerland; 2003. p. 1−176.

20. Rehman H, Chaudhry MA, Akhtar N. Assessment of sediment flushing efficiency of reservoirs. *Pakistan Journal of Science.* 2009;61(3):181–187.

21. Shen HW. Flushing sediment through reservoirs. *Journal of Hydraulic Research.* 2011;37(6):743−757.

22. Isam AH, Najla M, Fatima S, et al. Effectiveness Design parameters for Sedimentation of Calcium carbonate slurry. *International Journal of Chemical, Environmental & Biological Sciences.* 2003;1(2):224–228.

23. Pande PK. Sediment management in Hydropower plants. *International conference on Hydropower for sustainable development.* Uttarakhand, India; 2015. p. 1−17.

24. Apha. Method 208D Total non-filterable residue dried at 103-1050C in Standard methods for examination of water and wastewater, American public health Association, Washington, USA; 1975.

25. Lee CC, Shun DL. Handbook of Environmental Engineering Calculations. 2nd ed, McGraw-Hill Education, New York, USA; 2007. p. 1–1792.

26. EPA. Turbidity in water. Monitoring and Assessment, Pennsylvania, USA; 2012.

27. Fondriest E. Turbidity Total suspended solids and water clarity. *Fundamentals of Environmental measurements.* 2014.

28. Murphy S. General information on solids. USGS water quality monitoring, City of Boulder, Colorado, USA; 2007.

29. Langland M, Cronin T. A summary report of sediment processes in Chesapeake Bay and watershed. *Water resources investigation report* 03-4123. New Cumberland, Pennsylvania, USA; 2013. p. 1−122.

30. Michelbach S, Wohrle C. Settleable solids from combined sewers: Settling, storm-water treatment and Sedimentation rates in rivers. *Water Science & Technology.* 1994;29(2):95–102.

31. Chudley R, Greeno R. Building construction hardbook. Butterworth-Heinemann, Oxford, UK; 2008. p. 1−776.

32. Revel NMT, Ranasari LP, Rathnayake RM, et al. Estimation of sediment trap efficiency in reservoirs. *European international Journal of Science and Technology.* 2013;2(10):134–146.

33. Matthew DB. Operational performance of sedimentation basins. A master thesis submitted in University of Kansas; 2012.