MODELING SEDIMENT TRANSPORT IN VAAL-HARTS IRRIGATION SCHEME

SOUTH AFRICA USING POLYMATHS 6.1

Olumuyiwa I. Ojo[a], Fred O. A. Otieno[b] and George M. Ochieng[a]
[a]Tshwane University of Technology, South Africa.
[b]Durban University of Technology, South Africa.
[a]Corresponding author: ojooi@tut.ac.za

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Abstract: One of the major negative environmental impacts of large scale irrigation schemes is the problem of sediment transport. This greatly influences the sustainability of an irrigation system. The resultant erosion and deposition not only increase maintenance costs, but may result in an inequitable and inadequate distribution of irrigation water. Understanding the behaviour and transport of sediment allows efficient planning and reliable water delivery schedules, and ensures the controlled deposition of sediments, making maintenance activities more manageable. In this study, sediment transport in Vaal-harts irrigation canals was investigated in 2009 to estimate the quantity that leaves the cultivation area. The irrigation scheme situated in between the Vaal and Harts River Basin is about 36,000 ha in area. There is intensive cultivation in the area. The sediment concentrations, discharge and turbidity were monitored. Regression of sediment load on discharge was carried out using Polymaths 6.1. It was discovered that the average values of sediment concentration were 0.81 mg/l (July-September) and 0.95 mg/l (October – December).

Keywords: Discharge, Irrigation Canal, Pollution, Sediment, Turbidity

I. INTRODUCTION

Soil erosion and sedimentation are one of the major forms of soil and water degradation, which also directly affect sustainability of Irrigation schemes. Considering that over 80% of South Africa's land surface is covered by natural vegetation, the estimated annual soil loss of 2.5 t ha^{-1} is excessive and far exceeds tolerance levels and the estimated rate of soil formation of 0.31 t ha^{-1} yr^{-1}in the case of a 1 m thick solum of
a tropical soil [6]. An estimated 20% of the country's total surface area is potentially highly erodible. Sediment movement by erosion contributes significantly to shifts in soil fertility and is widespread in South Africa as reflected by the annual losses of 3 300 t N, 26 400 t P and 363 000 t K estimated by Du Plessis and Van der Merwe [1 & 2], while periodical floods can transport massive amounts of sediment and nutrients within catchments. The Demoina flood in 1984, for instance, deposited as much as 34 million tons of sediment in the Mfolozi flats [7], and using a siltation approach, it was estimated in 1985 that, according to the siltation load carried by the Tugela River, soil loss from the catchment area is as high as 4.4 t $ha^{-1}yr^{-1}$ with attendant effects on many water courses [1].Sediment transport is a major environmental problem that can arise in large irrigation projects by it pollution tendency. Sediment pollution often negates the benefits obtained from the development of these water resources.

Sediment is the most pervasive form of agricultural pollution. It is the largest pollution in terms of volume. Fine-grained sediment is especially most threatening because of its affinity for association with available pesticides and nutrients, susceptibility to erosion and transport, and its ability to pass through many applied erosion and sediment control measures. Sediment muddies rivers and lakes, reduces aesthetic appeal, and causes turbid conditions that interfere with the normal process of the aquatic ecosystem. In addition, sediment carries chemicals and metals that can be released to the water bodies. Thus accurate measurement of the sediment load in the water and of the chemical content of the sediment is important. Annual sediment yield and runoff are closely related. However, local factors, such as soils, geology, topography, land use, and vegetation may influence sediment yield much more than either runoff or drainage area. Lal, Greppi & Preti and Isikwue *et al* [5, 6, and 7] reported that transport to a surface water body from nonpoint sources is characterized by the response of the drainage area to defined rainfall events.

The effects of excessive sediment loading on receiving waters include deterioration in aesthetic value, a loss of reservoir storage capacity, changes in aquatic populations and their food supplies and an accumulation of bottom deposits that impose an additional oxygen demand and inhibit some advantageous benthic processes. Deposition of clay and silt in irrigation canals is a priority problem. Sediment is the most visible pollutant originating from non-point sources. Also, the finest sediment fractions are primary vehicles of other pollutants such as organic pesticides, metals, ammonium ions, phosphates, and other toxic materials.

In South Africa, pollution problem is increasing as water serves as a medium to transmit waste products and effluent produced by the growing population, industrialization and urbanization. Water quality is in particular jeopardy as a result of pollution, as water is a limited and strategic resource. Urbanization, industrialization, irrigation, inorganic fertilizers, weedicides and pesticides used by agriculture, polluted return flows and the recycling of water, largely contribute to water quality deterioration. Van der Merwe [8] also noted the particular importance of an increasingly heavy mineral salt load as salinity as it renders water less suitable for urban and industrial use while it has a devastating effect on food crops.

II. STUDY AREA

Vaal-harts Irrigation scheme (VIS) is the largest scheme with about 36,000 hectares of land developed for irrigation with wide ranges of crops cultivated such as Lucerne, cotton, maize, groundnuts and of late grapes, citrus, pecan nuts, water melon, peaches and olives. It has provided the country with high valued food basket as well as exporting to the neighboring countries.

VIS is relatively flat, but it slopes gently towards the Harts River, leaving the area as a basin. It lies within a valley with a maximum and minimum altitude of 1150 masi and 1050 masi respectively. The climate in the region is semi-arid to arid, with rainfall ranging from 500 mm to less than 200 mm per annual and evaporation reaching 2800 mm per annual towards the west. Flow in the Vaal River is perennial, fed from high rainfall and regulation upstream; the Harts River is characterized by high intermittent run-off. While the Molopo and Kuruman Rivers are endoric and typically cease to flow after some distance due to infiltration and evaporation [6].

During the past years of its operations, sediment deposition in and along the canal system posed serious threats to the scheme network. Sediment deposition caused many problems such as blocking the off take pipes and gates, raising canal beds and reducing canals slope, increasing the field levels and reducing canal flow capacity. This study thus assesses the changes in canal sections and makes some measurements to see if the canal design function is changed or not. Thus, the objectives of the study are to estimate the mean monthly amount of sediment flowing in VIS canal and also determine temporal variation in sediment yield for the period of study.

III. Materials and Methods

PARTICLE SIZE MEASUREMENTS

A sufficient large portion (mass) from the sample, which was brought from the field as suspended load was washed through the sieve no.200 (0.075μm) in order to obtain a mass of 500 g. This mass was placed in the oven at 110 °C for 24 hours to dry.

DISCHARGE AND VELOCITY MEASUREMENTS

The discharge at a given section could be measured by current method. The accuracy of the discharge measurement depended on the number of verticals at which the depth and the velocity were measured. A graduated tape determined the distance between verticals and the depth was measured with the graduated metal rod of the current meter. The velocity was measured at one or more points in each vertical. The velocity was then determined by counting the revolutions of the propeller of the meter during 50 seconds at every point. The average velocity was determined by the three-point method, which took the velocity observations in each vertical at 0.2, 0.6, and 0.8 intervals of the total water depth measured from the water surface. The average of the three values gave the mean or average velocity in the vertical.

SAMPLE COLLECTION

Sampling was done in three replications across the irrigation canals. It was collected once a month for a period of six (6) months July – December 2009. Samples were collected in one-litre (1000 cubic centimeter) plastic bottles. The turbidity was monitored in-situ using turbidity meter while the discharge was determined using float method. At collection, each sample was tagged with location and day. Then the samples were iced and carried to the laboratory and stored in the refrigerator to stabilize them till the analysis was completed. The water and sediment portions of the runoff samples were separated by centrifugation and filtering through what-man No. 42 filter paper. Polymath 6.1 was used to draw the graph and the chart before being imported into Microsoft Word.

POLYMATH 6.1

POLYMATH 6. X is a proven computational system, which has been specifically created for educational or professional use. The various POLYMATH programs allow the user to apply effective numerical analysis techniques during interactive problem solving on personal computers. Results can be presented graphically for easy understanding (www.google.com) accessed 14th April, 2010.

IV. RESULTS AND DISCUSSION

Sediment, discharge and sediment load are presented in Table II. The graphical relationship of the variables is represented in Figures I and II.

PLATE 1: SECONDARY CANAL FILLED WITH SILTS DOWN STREAM

PLATE 2: CANAL CLEANED OF SEDIMENTS

PLATE 3: A CLEAN MAIN CANAL

TABLE I: WEATHER CHARACTERISTICS OF THE VIS AT HARTS STATION

Area (ha)	35,000
Degree of latitude (south)	27
Degree of longitutide (east)	25
Average annual rainfall (mm)	442
Average annual maximum Temp (‘C)	26.6
Average annual minimum Temp (‘C)	10.5
Average annual Temperature (‘C)	18.6
Irrigation soil type	Hutton (sandy-clayey soil)

Source: [6]

TABLE II: VARIATIONS OF SEDIMENT AND DISCHARGES

Month	**Sediment (mg/l)**	**Canal discharge ($m^{3/}$ s)**
July	0.81	0.97
August	0.82	1.10
September	0.81	1.20
October	0.94	1.45
November	0.95	1.65
December	0.95	1.90

TABLE III: VARIATION OF TURBIDITY AND DISCHARGE

Month	Canal discharge (m^3/s)	Turbidity (NTU)
July	0.97	3.58
August	1.10	3.67
September	1.20	3.83
October	1.45	3.65
November	1.65	3.75
December	1.90	3.42

FIGURE I: SEDIMENT (MG/L) - DISCHARGE CURVE (M^3/S)

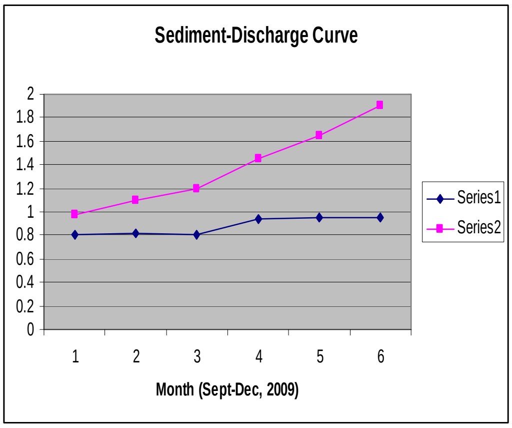
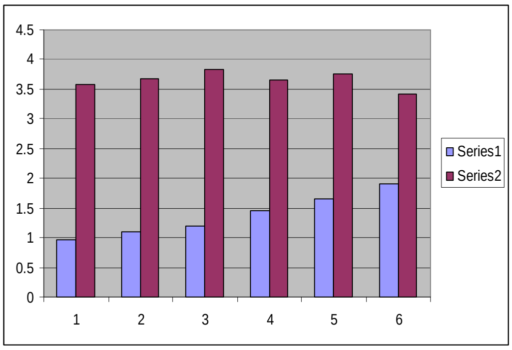


FIGURE II: VARIATION BETWEEN TURBIDITY AND DISCHARGE



V. CONCLUSIONS AND RECOMMENDATIONS

Sediment load in the VIS basin was studied. The sediment concentrations value was 0.81mg/l from July to September and 0.95mg/l from October to December. The sediment load increased with increase in canal discharge. Based on the results and discussion in the preceding section, the following conclusions can be drawn:

1. The deposition of sediment along the irrigation canals in VIS caused change in canal bed slope and cross section.
2. Farmers should be prevented from constructing temporary dykes across the canals to raise water levels.
3. High sediment concentration naturally existed mainly because of the type of irrigation type used: flooding, and sprinkler, unlike drip irrigation system which uses little water in order to prevent sediment deposition in the systems.

Canal maintenance and removal of coarse sediments from the up stream head reaches would prevent sediments from transporting further down stream the canal systems and to the fields. The coarse sediment transported to the fields caused changes of the fields' soil uniformity, which will negatively affect the planting practices.

In order to improve irrigation system by reducing the sedimentation problem through the irrigation canals and minimizing the sediment clearance costs the following recommendations are made:
1. The upstream end of the irrigation canals need more frequent sediment clearance than the downstream reaches in order to keep its bed level as constructed in order to increase the diverted water to the canals and to reduce the coarse bed materials transportable to the downstream reaches.
2. The canals intakes should be adjusted in order increase the diverted water to the canals thus reducing the coarse bed material that entered to the canals.
3. In order to minimize the bed load sediment in the irrigation canal flow, sediment extractor could be constructed at the canals upstream.
4. Several settle basins could be constructed along the canals especially at the points where much sedimentation occurs. These settle basins would be easer to clean than clearing the entire canal reaches.
5. For maintenance purposes the irrigation canals could be divided into several sections with specific users being responsible for each section close to their lands. The maintenance and cleaning of the irrigation canals should be the responsibility of the various users (farmers) within their allotted irrigated area. This would minimize the sedimentation problem and avoid the bed-load sediment transport to the fields, and would decrease the maintenance cost.

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REFERENCES

[1] De Villiers, M.C., (2002) 1902-2002 Centenary report of the Agricultural Research.
[2] Du Plessis, H.M. (1991). *Researching and applying methods to conserve natural irrigation resources*. Proc. South. Africa. Irrigation. Symp. 61-69. Durban, South Africa.
[3] *Greppi, M. & Pretti, F. (1999). Water Quality in Agriculture. In CIGR Handbook on Agricultural Engineering: Land and Water Engineering (pp. 507-544).*
[4] Isikwue, M.O., Idike, F.I., & Chukwuma, G.O. (2001). Seasonal Nutrient losses from River

Ukoghor Agricultural Watershed. *Proc. Nigeria Inst. of Agric Engineers 23,* 229 – 234.

[5] Lal, R. (1999). Water Quality Effects of Tropical Deforestation and Farming System on Agricultural Watersheds in Western Nigeria. In Lal, R., and Steward, B.A. (Eds.) *Advances in Soil Science Processes and Water Quality* (pp. 273 – 301). London: Lewis Publishers.

[6] Ojo, O.I., Otieno, F.A.O. & Ochieng, G.M. (2009). *Irrigation Problems and Research needs in South Africa: A review of Vaal Harts Irrigation Scheme*. World Academy of Science, Engineering and Technology WASET Conference, September 23-25, 2009. Amsterdam, the Netherlands. ISSN 2070-3740.

[7] Scotney, D.M. & Dijkhuis, F.J., (1990). Changes in the fertility status of South African soils. *S. Afr. J. Science 86*, 395-402.

[8] *Van der Merwe, A.J. (1995). Wise land use: The basis for sustainable growth and development in South Africa. Proc. ARC-ISCW Wise Land Use Symp. 2-8. Pretoria, South Africa.*