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Determining Sediment Load of Awash River entering into Metehara Sugarcane Irrigation Scheme in Ethiopia

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Abstract
A study was undertaken to estimate the sediment concentration that enters into irrigation system of Metehara sugar estate from Awash River. Sediment samples were taken from Awash River and irrigation canals. The samples were analyzed for sediment concentration and particle size distribution. Measurements of suspended sediment transport in Awash River have shown that very high sediment concentrations occur during flood flows. Suspended sediment loads, estimated over one year period (Nov. 2013 – Oct. 2014), showed seasonal variations reflecting the seasonal rainfall distribution. Average annual sediment yields that enter the irrigation system through Merti and Abadir intake structures were 106,352.59 tons and 90472.54 tons, respectively. Average annual sediment yields in Awash River at Merti Bridge were 658,120 ton and increasing during rainy season. Capacity of the canal system and night storage reservoirs is reduced by sediment deposits and the estate cost huge amount of money for annual reservoirs and canals maintenance. There should be effective maintenance and monitoring of the canals and the reservoirs through regular de-silting and cleaning of the canals. Therefore, it is recommended to construct settling basins at the intake structures on the bases of the criterion that no sedimentation would occurred.
Keywords: Sediment, Discharge, Awash, Canal, Reservoir, Metehara

1. Introduction

Sediment deposition in irrigation canals results in rising canal bed levels, reduced canal capacities, and problems in supplying the required amounts of water to some or all parts of the irrigated area (Chancellor et al., 1996). Estimating the rate of sediment deposition and the period of time at which the sediment would interfere with the useful functioning of a reservoir and irrigation canals is the most important practical and critical problem related to performance of reservoirs and irrigation canals.

Awash River Basin covers a total area of some 116,000 km^2 and extends from the centre of Ethiopia in a north easterly direction to Djibouti boarder. The basin is bordered to the north by the Danakil River basin, to the west by the Abbay, to the south-west by the Omo-Gibe and Rift Valley Lakes, to the south-east by the Wabi Shebele River and to the east by the Republic of Djibouti, the Somali Democratic Republic and the Aysha Dray Basin. The main physiographic components of the Awash Basin are the Ethiopian Plateau and the Rift Valley, which widens to the north into the Afar Triangle (MoWR, 2007).

According to DHV (1983) large quantity of sediments is entering into Metehara irrigation canal system through the intake. Due to the absence of silt trap at the intake, the problem of siltation is more exacerbated. The capacity of the canal system and night storage reservoirs is reduced by sediment deposits to such an extent that the discharge requires for irrigation cannot be maintained (DHV, 1983). Zeleke (2007) also revealed that sedimentation of conveyance and off take structures and lack of maintenance in sub-laterals among others are the main causes for failure in optimal performance.

Large quantity of sediment load also decreases the expected life time of reservoirs from 6 years to 3/4 years. Currently the estate is doing annual over all maintenance for reservoirs and irrigation canals as a measure to reduce sedimentation load which requires extensive excavation/dredging of canals and reservoirs to maintain the capacity at acceptable level. Removal of sediment from reservoirs and irrigation canals is very costly and time consuming operation and causes structural deformation which leads to reduction of discharge carrying capacity. Annually the estate incurred more than 3 million birr for operation and maintenance (for desilting) of irrigation canals and night storage reservoirs.

According to Zeleke (2007) unless the estate prevents the sediment entering into the canal system it continues to become a problem not only for the performance of off takes and conveyance structures but also to the discharge measuring structures used. As such it is crucial for the estate to look for alternatives to exclude sediments entering the system.

Currently the estate is facing the siltation problem. However, to recommend alternative options to overcome the problem the concentration as well as the type of sediment entered into the estate is not known. The number of data available on sediment concentrations and grain size distribution during the whole year is very limited. The information generated from this study would be important for designing a sound settling basin for the diversion weirs of Metehara sugar estate. Therefore the objective of this study was to estimate the concentration and type of sediment load of Awash River entering into Metehara sugar estate irrigation canal system.

2. Materials and methods

2.1. Description of the study area

The experiment was carried out at Metehara Sugar Estate, which is located in the upper valley of Awash River sub-basin of Ethiopia. It is situated at an elevation of 950 m above sea level with latitude of 8°50´N and longitude of 39°55´E. The mean annual minimum and maximum temperatures are 18.10^{0}C and 33.5^{0}C, respectively. The average annual rainfall is about 550 mm. Minimum and maximum relative humidity is 35.6% and 88%, respectively.

Furrow irrigation method is used to irrigate sugarcane fields. Two diversion weirs and intake head works found at Merti and Abadir constructed on Awash River are used as irrigation water abstraction. Merti intake structure which is located at downstream of Abadir serves to irrigate 7,087 ha (for the main estate and North section) while Abadir intake structure serves to irrigate 3,156 ha (for Abadir site). The main intake at Merti is made of concrete while the diversion structure at Abadir is made of gabion. Average annual water abstracted from both diversion weirs is about 266.7 Mm^3 (five years average: 2008/09-2012/13). The irrigation system at the estate is based on irrigation during 9 hours per day and night storage of the water during the following 15 hours. For this purpose 25 night storage reservoirs have been constructed, where the water holding capacity ranges from 6,500 to 93,000 m^3. More than 1,200 km of canal network supplies irrigation water to sugarcane fields. The water delivery infrastructure consists mostly of unlined canals but with some lined canals in particular areas of the estate. There are also 6 electrically driven pumping stations in the estate to provide water to areas which are situated too high for gravity irrigation.

Awash River basin has an annual flow of 4.6 billion m^3. The Awash river basin divided into seven sub-basins: Upland Basin (includes the headwaters and extends down to Koka Dam covers 9.6% of catchment area); Western Highlands (includes left bank tributaries from Kesem River to Logiya River covers 22.2% of catchment area); Upper Valley (from Koka Dam to Awash Arba covers 11.2% of catchment area); Middle Valley (between Awash Arba to Adaitu covers 14.0% of catchment area); Lower Valley (between Adaitu and Logiya covers 3.5% of catchment area); Lower Plains (downstream of Logiya, where the Awash River meanders and terminates at Lake Abe covers 5.6% of catchment area); and Eastern Catchment (area on the right bank downstream of Koka Dam covers 33.9% of catchment area).

2.2. Methodology

The study was conducted for one year starting from Nov, 2013 to Oct, 2014. To see effect of flooding sedimentation and time variation of sediment concentration sampling was taken two to four days per month for nine months. Averages of two to four sampling days were considered as the specific month sediment concentration and discharge rate.

Suspended sediment flow samples were measured at the entry point of the main canals (for both Merti and Abadir) to estimate the quantity of silt diverted from Awash River using depth integrated US D-49 sampler. Discharge measurements of main canals were done by USGS Type AA current meter mounted on US D-49 sampler weight. To assess the variability of sediment load along the canal sections, sediment flow was taken from two different points of the main canals sections (Merti and Abadir). Measurement of suspended sediment from Awash River at Merti Bridge was also done using depth integrated US D-48 suspended sediment sampler. During 2013/14, 30 suspended load samples were taken from Awash River at Merti Bridge. Discharge measurement of Awash River was done by USGS type AA current meter mounted on US D-48 sampler weight. Discharge measurement for Awash River and main canals was taken together with the sediment measurements. The weight samplers were suspended on cableway for Awash River and Merti main canal and for Abadir main canal Type A crane with four-wheel truck was used to suspend the weight sampler (Rickly, 1997).

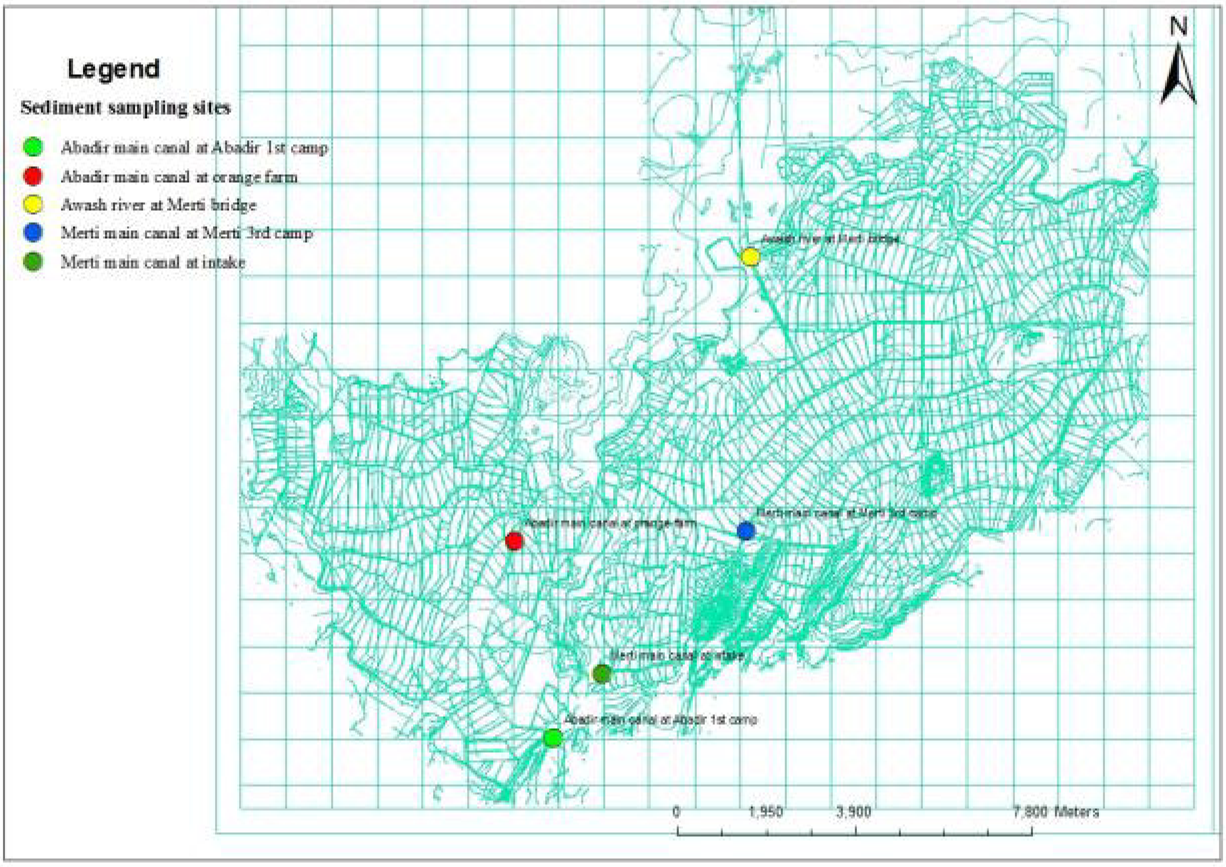

Figure 1. Sediment load sampling sites at Metehara sugar estate

The suspended sediment load was measured in three verticals across the width of the canals and the river. The sampler lowering and raising using an equal rate, collect one sampler at each vertical and the sampler continued to take its sample throughout the time of submergence. The measurements were taken at three points (as the case in the sediment sampling) in the vertical at 0.2d, 0.6d and 0.8d where d is the flow depth (Xiaoqing, 2003).

Bedload measurement was taken from Awash River at Merti Bridge using DM-54 sampler. Estimates of bedload were obtained from samples caught in a device which is lowered to the streambed for a measured time then brought up for weighing the catch. The bedload was measured in three verticals across the width of the river.

2.3. Data Analysis

To determine the concentration and particle size distribution of the sediment load (flow-weighted as well as bed material) analysis was done at Metehara research station laboratory. The samples were transported to the laboratory and weighed as soon as they were received. The sediment concentration was calculated as the weight of sediment divided by the volume of sediment-water mixture and expressed in milligrams per liter (mg/l).
The following equations were used to determine the different sedimentation parameters:
Sediment concentration (C_s) in parts per million was computed:

$$C_s = \left[\frac{\text{Weight of sediment}}{\text{Weight of sediment - water mixture}} \right] 10^6 \tag{2.1}$$

Concentration values are merged with discharge values representing a selected time interval and summed to derive daily suspended-sediment discharges using the equation (Hudson, 1993):

$$Q_s = Q_w * C_s * K \tag{2.2}$$

Where: Q_s = suspended-sediment discharge (tons/day);
Q_w = water discharge (m^3/s);
C_s = mean concentration of suspended sediment in the cross-section (mg/l);
k = a coefficient based on the unit of measurement of water discharge that assumes a specific weight of

2.65 for sediment, and equals 0.0864 in SI units.
Velocity area method is used to determine Awash River and canals discharge.

$$Q = VA \tag{2.3}$$

Where, Q = the total flow (m^3/s)
V = the velocity (m/s)
A = Cross sectional area of the canal within wetted perimeter (m^2)

The sediment samples were collected to determine sediment particle size analysis. Sieve analysis was conducted for coarse sediment particles of the bed material. Hydrometer method was used for analyzing the particle sizes analysis passed through 2 mm sieve.

For analyzing the collected data of suspended and bed load sediments, river and canal discharges, and sediment particle size analysis descriptive statistics using the above mentioned formulas were used. The sediment-transport curves were computed using the linear regression technique. For determine the relation equation, 30 samples of suspended-sediment concentration and water discharge obtained at Awash River at Merti Bridge, during the 2013-14 are used.

3. Results and discussion

3.1. Analysis of sediment load at Awash River at Metehara

The maximum flow of Awash River during the study period at which suspended load measured for the specific sampling days was 37.2 m^3/s on March and the maximum measured sediment load concentration of the river for the specific sampling days was 3666.4 mg/l on July. The average annual suspended sediment transport of Awash River at Metehara was 658,120.10 ton (1803.07 ton/day). Paulos (2004) estimated the suspended sediment load of Awash River as 579 ton/day around Wonji pump station for dry period. The sediment concentration increased during rainy season especially in the month of July. High sediment concentrations with low flows are occurring at the beginning of the rainy season (Figure 2). The amount of rain falling during rainy season upstream of Koka dam was small as a result the reservoir of Koka could not store enough amount of water. So the expected discharge from Awash River below Koka dam at Metehara was small as seen from Figure 2.

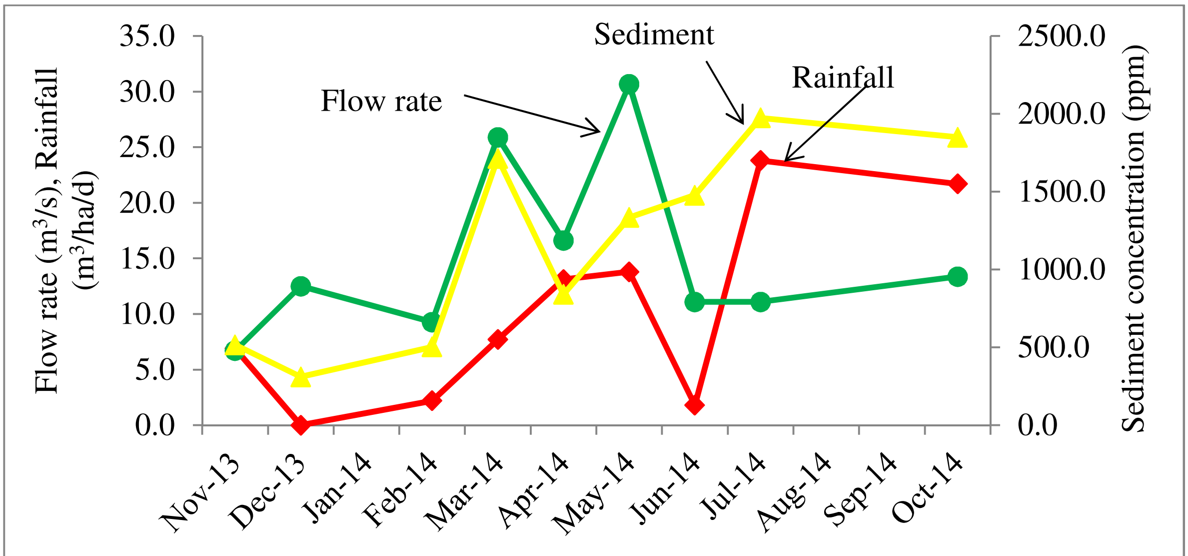

Figure 2. Comparison between rainfall, flow rate and suspended sediment concentration of Awash River at Merti Bridge, average of sampling months

NEDECO (1972) as cited in (DHV, 1983) has estimated the total annual sediment load entering the canal system as 65,000 m^3. DHV (1983) arbitrary estimated the sediment load based on NEDECO (1972) to be 80,000 m^3. The current study estimated the sediment load of Awash River as 248,347.21 m^3. This proved that the sediment load increase due to the effect of soil erosion between Koka dam and Metehara intake. In addition, there is a strong possibility that Koka reservoir outflow have high sediment concentration due to short-circuiting and re-suspension of pre-deposited sediment (Paulos, 2004).

The suspended sediment transport curve for Awash River at Merti Bridge is shown in Figure 3. Using power-type regression to create rating curves, i.e., fitted equations, the relation between sediment discharge and water discharge showed that greatest coefficient of determination (R^2 = 0.6) and the data produced a rating equation of the form:

$Q_s = 17.496Q^{1.5905}$
where Qs = Suspended sediment load (t/day)
Q = Flow discharge (m^3/s)
Suspended sediment load and discharge were strongly and positively correlated (R^2 = 0.6). From the whole sampling days of the year, the highest rates of measured suspended sediment transport across the study period occurred during high water flow sampling day in March.

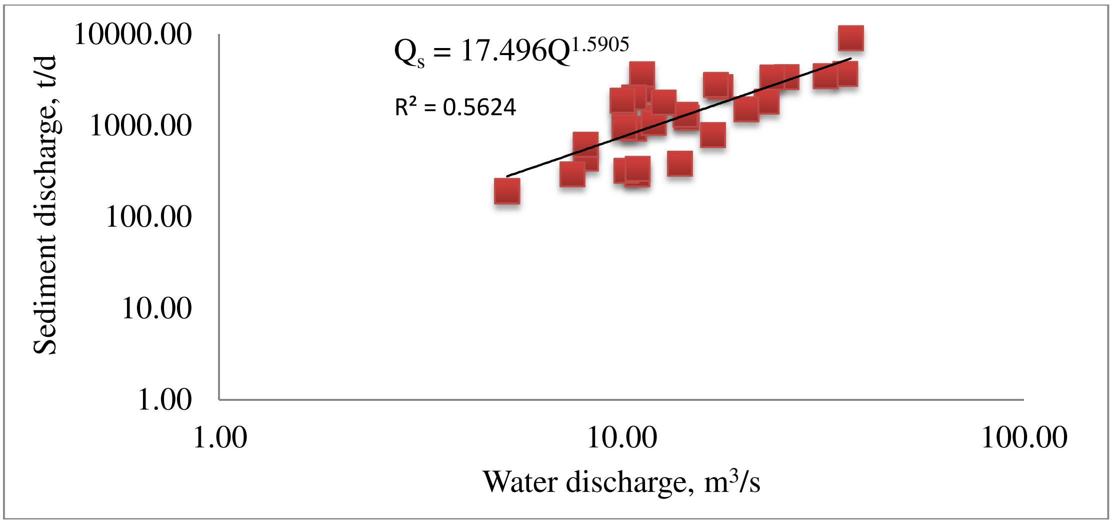

Figure 3. Sediment transport curve for Awash River at Merti Bridge, 2013/14 water year

Measured bed load was as low as 385.87 ton/day to 1975.38 ton/day. The average bed load transport rate of Awash River around Metehara was 955.27 ton/day. Average annual suspended sediment load was found to be generally greater than average annual bed load on Awash River. The bed load transport rate of Awash River at Metehara is estimated to be 55.4% of the suspended load. Paulos (2004) estimated the bed load transport rate of Awash River around Wonji pump station as 38% of the suspended load for the dry period.

Measured bed load was more uniform across the study period than suspended load. The relation between bed load sediment discharge and water discharge of Awash River based the available data using power-type regression showed strong positive correlation (R^2=0.97). The rating curve equation looks as follow:
$Q_b = 62.47Q^{0.955}$
where Qb = Bed load sediment (t/day)
Q = Flow discharge (m^3/s)

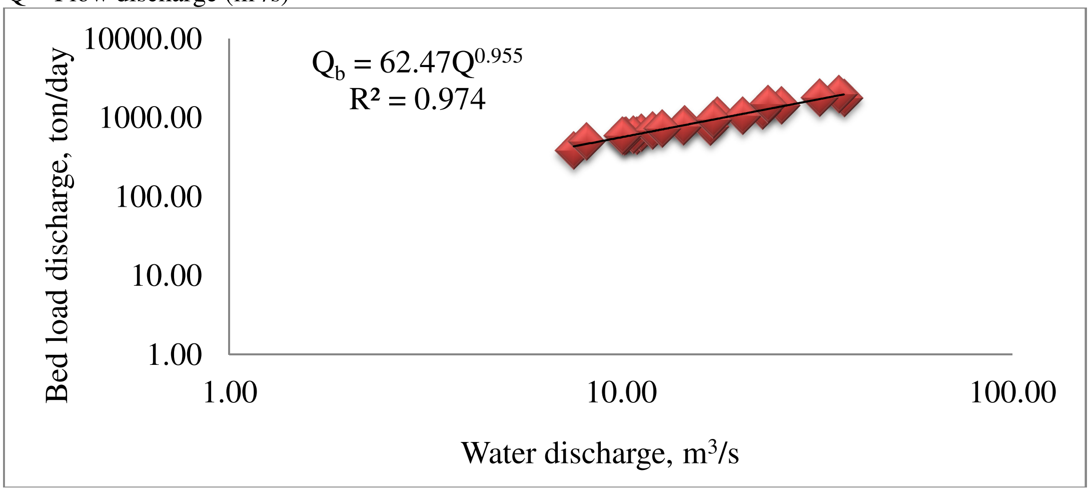

Figure 4. Bed load sediment transport curve for Awash River at Merti Bridge, 2013/14 water year

3.2. Analysis of sediment load entering into Metehara sugarcane plantation irrigation system

To determine amount of sediment entering into Metehara sugarcane plantation suspended load was measured at two main canals (Merti and Abadir) at two different places of the irrigation system. The average annual sediment concentration for Merti main canal around the intake structure was found to be 106,352.59 tons, while around Merti 3rd camp was found to be 99,582.97 tons. Whereas, the average annual sediment concentration for Abadir main canal around the intake structure was found to be 90,472.54 tons, while around orange farm was found to be 71,197.29 tons. The average annual suspended sediment transport was generally deceased downstream of both intake structures. Carrying capacity of Merti main canal is almost double of Abadir main canal; due to this sediment concentration of Merti main canal is higher than that of Abadir main canal.

The current study estimated the sediment load entering into the irrigation system at Merti intake structure as 322.28 ton/day, while that of Abadir intake as 274.16 ton/day. The Abadir intake structure is found at upstream of Merti intake structure. Carrying capacity of the main canal at Abadir is almost half of Merti main canal but the sediment concentration at Abadir was 85% of Merti. From this it can be concluded that high sediment load was entering through intake structure of Abadir. The intake structure at Abadir is made of gabion and lack maintenance as a result large quantity of sediment was passing through the structure. In addition to this, erosion of the unlined canal due to high scoring potential of the irrigation water come from the main canal could be the possible cause for high sediment load. Especially at Abadir, velocity of the water in the canals measured reaches as high as 1.37 m/sec.

The sediment load concentration on the irrigation canals is believed to be due to deforestation of Awash River basin which takes the major contribution, erosion of unlined canals, backfilling of de-silted sediment from canals and cattle activities around the canals.

According to MoWR (2007) report the degradation of Awash River upper catchment has serious environmental and economic impacts. The degradation comprises primary soil erosion, and secondary erosion and transport of the material via gullies and small drainage channels. Sections of the river bed in the middle and lower catchment are aggrading as the sediment carried down from the upper catchment is deposited, resulting in more frequent and extensive flooding. The high silt load in the river also reduces capacity and thus the effective life of dams.

According to Ahmed (2006) as cited in Awulachew et al., (2008) sedimentation in Sudan creates a serious negative impact on irrigation canals such as reduction of irrigated area and decreases in crop productivity. It also increases the cost of operation and maintenance. It is estimated that, in Sudan, almost 97% of the sediment entering the irrigation systems is smaller than 63 microns (i.e., predominantly silt and clay). Tukur et al. (2013) estimated the suspended sediment concentration that was entered into the irrigation canal system at Nigeria as 8474.4 ton per annum and the deposit consists of a fine sand fraction (76.3%) with a small amount of clay and silt of about 12.04% and 11.66%, respectively.

3.3. Sediment particle size analysis

The size and distribution of the gravel fractions were determined by sieve analyses whereas sand, silt and clay fractions were determined by hydrometer methods. The grain size distribution was estimated for the bed load, the primary grain size class in transport was sand. From the hydrometer reading it was found that 90% of the grain size below 2 mm was sand. The sieve analysis showed that 91.5% consists of coarse sand with a diameter of 0.212 - 2 mm. DHV (1983) estimated the fine and very fine sand at the intake structure as 80% from the sieve analysis. Fine gravel was noted in bed load samples but not as significant (i.e. 1.3%) fraction. Coarse sand and bigger grain sizes are transported mainly as bed load. A research conducted on Awash River at Wonji by Paulos (2004) indicated that that 90 - 95% of the sediment entering the canal system was smaller than 0.063 mm and 55 – 60% was smaller than 0.002 mm.

During flooding there was a tendency for coarse grains also to move into suspension. The cumulative size distribution of various sediment sizes by mass can be approximated by a log-normal distribution, as shown in Figure 5.

According to MacDonald (1990) for unlined canals to operate with minimal maintenance, the sediment supply should not exceed about 100 mg/l on average, with no material coarser than about 0.3 mm. Except in those situations where continuous desilting is feasible, a settling basin is required to store the settled sediment until the time comes for it to be flushed out (e.g. intermittent flushing with canal closure). The arrangements for storage and desilting are an essential feature: failure to adhere to strict operational rules for sediment removal will cause the system efficiency to drop rapidly, with serious effects on the canal system itself.

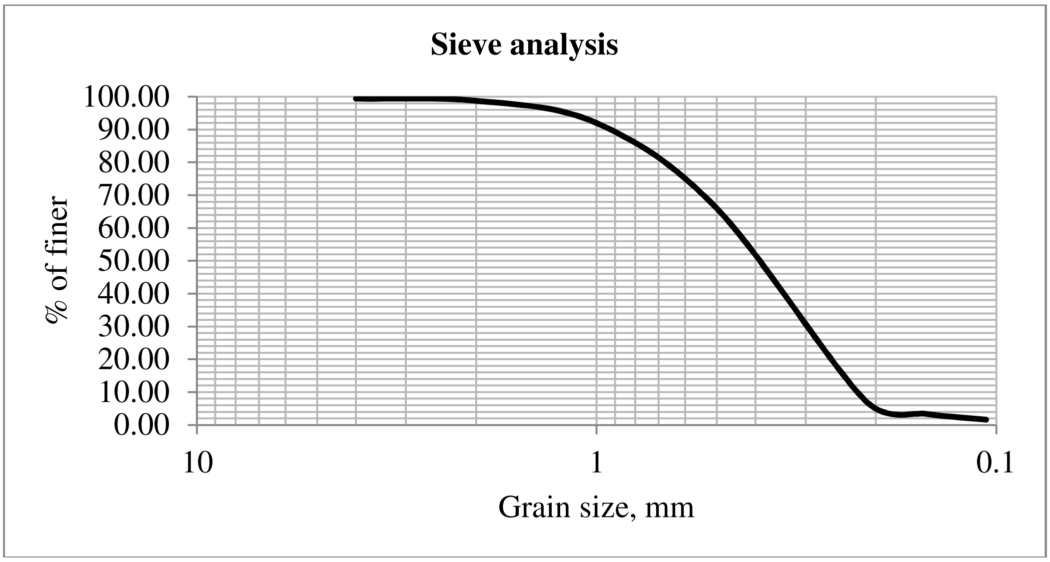

Figure 5. Bed material grading curves of Awash River

4. Conclusion and recommendation

Silt accumulation on irrigation canals and night storage reservoirs reduces water transporting capacity of canals and reservoirs which would influence directly the irrigated areas. From the study it is concluded that high rate of sediment yield was entering into the canal system. Silt deposition in irrigation canals of Metehara sugar factory showed an increasing trend for the last 40 years due to high silt content of Awash River in particular during period of rainy season. Average annual sediment yields that enter the irrigation system through Merti and Abadir intake structures were 106,352.59 tons and 90472.54 tons, respectively. Average annual sediment yields in Awash River at Merti Bridge were 658,120 ton and increasing during rainy season.

Based on the results obtained, the following recommendations are forwarded:

- The estate practiced annual maintenance of canals and reservoirs manually and using excavators to maintain the capacity at acceptable level. Therefore, this practice should be continue through regular and effective de-silting and cleaning of the canals and reservoirs as an alternative for short period solution.
- Annual de-silting costs are excessive so controlling sediment at the entrance to the canal system would be more effective and efficient than extensive maintenance of canals and reservoirs after it has entered to the system. Therefore, it is recommended to design and construct settling basins at the intake structures (for both weirs) on the bases of the criterion that no sedimentation would occurred.
- Flood control measures and integrated watershed management projects launched by Ministry of water, irrigation and energy should be continued to reduce soil erosion and related problems. The estate should take over the leading to coordinate these measures.

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