Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 5, Issue, 5, pp.1224-1228, May, 2013

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

EVALUATING THE EFFECTIVENESS OF BEST MANAGEMENT PRACTICES UNDER CLIMATE CHANGE SCENARIOS IN GILGEL GIBE-1BASIN-ETHIOPIA

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ARTICLE INFO

Article History:
Received 12th February, 2013
Received in revised form
13th March, 2013
Accepted 16th April, 2013
Published online 12th May, 2013

Key words:
BMPs,
Climate Change,
SWAT model

ABSTRACT

Gilgel Gibe 1 hydropower reservoir is highly threatened by siltation/sedimentation problem due to excessive erosion from the upper catchment. To mitigate the serious erosion from the upper catchment and reduce the sediment delivered to the reservoir so as to increase the life span of the project, implementing a suite of best management practices (BMPs) is needed. However, as climate changes, the effectiveness of the BMPs will be affected. Hence, understanding the effectiveness of the best management practices as climate changes will be important for better planning of watershed management. The objective of this study was to evaluate how the BMPs performance varies due to changes in precipitation and temperature using the Soil and Water Assessment Tool. Sediment loads from the whole watershed was estimated on the annual basis before and after implementation of agricultural BMPs. Climate change data were obtained by the delta change method. The Soil and Water Assessment Tool model was calibrated using Sequential Uncertainty Fitting 2(SUFI2) to simulate the sediment load. The results of the study indicate that the BMPs tested are sensitive to climate change. Therefore, further investigations should be made and caution should be exercised in the decision making process.

INTRODUCTION

Heavy sedimentation has been experienced by Ethiopia's existing dam reservoirs and lakes and is a very real risk to the lifespan of new hydropower dams. Wolancho (2012) summarized the investigations made by different researchers on the effects of sedimentation on some of the existing dams of Ethiopia. The expected reduction in capacity or the capacity reduced shows the heavy sedimentation problem experienced by the Ethiopian dams. Gilgel Gibe 1 dam is one of the hydro dams heavily threatened by the siltation/sedimentation problem as a result of serious soil erosion from the upper catchment. Devi *et al*., (2007) conducted a cross-sectional study and assessed the siltation and nutrient enrichment level of the Gilgel Gibe 1 dam reservoir. From their study they found that siltation and nutrient enrichment were the major problems in this reservoir. The problem of sedimentation in Gilgel Gibe 1 will also affect Gilgel Gibe 2, which uses the water released from Gilgel Gibe 1 for power generation. Gilgel Gibe 2 is a cascade hydropower project to Gilgel Gibe 1. Siltation is the major problem of Gilgel Gibe 1 dam. Currently there are ongoing efforts to implement agricultural best management practices (BMPs) to mitigate the soil erosion from upper catchment and reduce the sediment yield to the reservoir. BMPs have been widely applied on hot spot areas of a watershed to reduce pollution. For instance, Betrie *et al*., (2011), Arabi *et al*., (2007), Bracmort *et al*., (2006) and Tuppad *et al*., (2010) used this approach. However, considerable uncertainty exists regarding the effectiveness of BMP implementation on pollutant load reduction under anticipated future changes in climate (Van Liew *et al*., 2012). On the other hand studies conclude that climate change have a significant impact on water quantity and quality of watershed systems (Woznicki *et al*., 2011). In Ethiopia, the climate change will exacerbate the natural resources degradation and also impose additional challenges on water and energy supply, food security and poverty reduction efforts. As climate changes, the magnitude of sediment yield from the subbasins of the watershed and the sediment flux at the outlet of the watershed may increase extremely, to the extent that the effective BMPs under current condition may not be appropriate to treat these conditions. Demissie *et al*., (2013) investigated the climate change impact on streamflow and simulated sediment flux to Gilgel Gibe 1 hydropower reservoir for the future period of the 2050s. Therefore, the objective of the study was to examine how future climate change scenarios will impact the effectiveness of BMPs on reducing the simulated sediment yield from the subbasins and sediment flux at the outlet of Gilgel Gibe 1 basin. To better understand the impact of future climate scenarios on BMPs effectiveness, and to assist the watershed development planners, the Soil Water Assessment Tool (SWAT) hydrological model was used. The SWAT model is widely used in Ethiopia with satisfactory results, and most of the SWAT application concentrates on the Blue Nile River Basin.

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Description of the study area

The Gilgel Gibe 1 project is located in the south-western part of Ethiopia, in Oromia Regional State.The Gilgel Gibe 1 reservoir is located at 7^{o}49`52.45``N latitude and 37^{o}19`18.79´´E.The Gilgel Gibe 1 catchment which drains into Gilgel Gibe 1 reservoir is located 7$^o$ 19´07.15´N to 8$^o$12´09.49´´N latitudes and 36$^o$31´42.60´´ E to 37$^o$25`16.05´´E longitudes. The project is purely a hydropower scheme, with an installed capacity of 180MW, aimed to increase energy and power supply to the national grid. The reservoir has a live storage capacity of 657x10^{6}m^3. The catchment area of the Gilgel Gibe basin is about 5125km^2 at its confluence with the great Gibe River and about 4225km^2 at the dam site.The basin is generally characterized by high relief hills and mountains with an average elevation of about 1700m above mean sea level. The basin is largely comprised of cultivated land. In general terms, the Gilgel Gibe basin is characterized by a wet climate with an average annual rainfall of about 1550mm and average temperature of 19°C The seasonal rainfall distribution takes a uni-modal pattern with its maximum during the summer and minimum during winter, influenced by the inter-tropical convergence zone (ITCZ). Fig.1 shows the location map of Gilgel Gibe 1 basin.

METHODOLOGY

Soil and Water Assessment Tool Model description

SWAT is a continuous daily water balance model which was developed to assist water resource managers in assessing the impact of management practices on water, sediment, and agricultural chemical yields in large ungaged basins (Arnold *et al*., 1998, Arnold *et al*., 1999). For modeling purposes the catchment is divided into a number of subbasins which will be divided further into hydrological response units (HRU) based on soil type, land use/ land cover and slope classes. The SWAT model has two alternatives for computing surface runoff, and three methods for estimating potential evapotranspiration. For this study the USDA-Natural Resources Conservation Service run off curve number (CN2) method was used to estimate the surface runoff (USDA,1999), and evapotranspiration was estimated using the Penman – Monteith method (Monteith,1965). The SWAT model calculates the surface erosion within each HRU with the Modified Universal Soil Loss Equation (MUSCLE) (Williams, 1975). MUSLE predicts sediment yield as a function of surface runoff volume, peak runoff rate, area, soil erodibility, land cover, land support practices, topography, and percent coarse fragments in top soil layer. Channel sediment routing in SWAT is based on the maximum amount of sediment that can be transported from a reach segment, which is a function of peak channel velocity (Neitsch *et al*., 2011). Sediment routing is dominated by two processes: deposition and degradation. Degradation occurs when sediment concentration is less than maximum amount of sediment that can be transported from a reach segment, whereas deposition occurs when sediment concentration is greater than the maximum amount. The SWAT model is well formulated and considerable detail is provided regarding model structure, algorithms, and data input, and viewing of test results. SWAT version 2009 was used for this study. For detail description of SWAT model refer (Neitsch *et al*., 2011).

SWAT Model set up

The SWAT model requires various spatial datasets and daily weather data for model setup. The spatial data required includes the digital elevation, land use, and soils data. The landcover/landuse and the soil data for the study area were obtained from the Waterbase web site (http://www.waterbase.org/download_data.html) as provided by Dr Abbaspour of Eawag (http://www.eawg.ch/index_EN). The soil map produced from (FAO, 1995) and provided has almost 5000 soil types at a spatial resolution of 10kms. Some properties for two layers, 0 to 30 cm and 30-100 cm depth are also provided (Leon, 2011). The land cover classes in this area are Dryland Cropland and Pasture (CRDY, 36.7%), Grassland (GRAS, 15.6%), Savanna (SAVA, 14.4%), Evergreen Forest (FOEB, 22.7%), Mixed Forest (FOMI, 9.9%) and Cropland/woodland mosaic (CRWO, 0.7%). The soil types in the area are Nitosols. To delineate the watershed and extract the topographic parameters a 90m digital elevation map (DEM) was obtained from the consortium of spatial information (Jarvis, 2008). Using these spatial data sets and providing three slope classes i.e. 0 – 10%, 10 – 20%, and greater than 20%, 369 HRUs were derived. All the HRUs with landuse of Dryland, Cropland and Pasture were targeted for BMPs application and the impact of climate change was evaluated. The recorded daily weather data required to run the SWAT model were obtained from the National Meteorology Agency (NMA) of Ethiopia. The daily data of rainfall, maximum and minimum temperature, wind speed, Sunshine duration and relative humidity for two stations, namely Jimma and Sekoru were obtained. The data covers a period of 26 years from 1980 to 2005.

Sensitivity analysis, model calibration and performance evaluation

Before calibration, sensitivity analysis was carried out by using One-factor-At-a-Time (LH-OAT), an automatic sensitivity analysis tool implemented in SWAT. All the 27 flow- related parameters were taken and the eight most sensitive parameters depicted in Table 3– with their fitted values were selected according to their sensitivity for calibration. Their fitted values are obtained through calibration using Sequential Uncertainty Fitting-2 (SUFI-2) (Abbaspour *et al*., 2007). SUFI-2 algorithm accounts for several sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. The degree to which uncertainties are accounted for is quantified by a *P-factor* which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling (Abbaspour *et al*., 2007). Another measure quantifying the strength of a calibration or uncertainty analysis is the R-factor which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. The goodness of calibration and prediction uncertainty is judged on the basis of the closeness of the *P-factor* to 100% and the *R-factor* to 0.The average thickness of the 95PPU band (P) and the R-factor are calculated by Eq.(1) and Eq.(2).

$$P = \frac{1}{n}\sum_{i=1}^{n}(Q_U - Q_L) \qquad (1)$$

$$R - factor = \frac{P}{\sigma_Q} \qquad (2)$$

Where: n is the number of observed data points, Q_U and Q_L are the 97.5th percentiles and 2.5th percentiles of the cumulative distribution of every simulated point respectively. σ_Q is the standard deviation of the measured variable Q. Next to calibration and validation, the model was evaluated to verify its robustness. In this study, the following methods were used (i) Nash – Sutcliffe efficiency (NS), and (ii) correlation between observed and simulated flows. The NS is computed as the ratio of residual variance to measured data variance. The NS is calculated using Eq. (3).

$$NS = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - Q^{mean})^2}\right] \qquad (3)$$

The coefficient of determination R^2 value is an indicator of the strength of the linear relationship between the observed and simulated values. It ranges from 0 to 1, with higher values indicating better agreement. It is calculated using Eq. (4).

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Q_i^{sim} - Q_{mean}^{sim})(Q_i^{obs} - Q_{mean}^{obs})\right]^2}{\sum_{i=1}^{n}(Q_i^{sim} - Q_{mean}^{sim})^2\sum_{i=1}^{n}(Q_i^{obs} - Q_{mean}^{obs})^2} \qquad (4)$$

Representation of Best Management Practices in Soil and Water Assessment Tool

Ten important agricultural conservation practices were selected for representation with the SWAT model. However, the selection of BMPs and their parameter values are site specific and should reflect the study area reality (Betrie *et al*., 2011). For this study we selected the conservation practices to be implemented based on Ministry of Agriculture and Rural Development (MoARD, 2005) guideline. For the baseline condition (scenario 0) the input parameters are based on the calibrated SWAT model parameters for streamflow and the default SWAT values for sediment flux. For scenario 1 and scenario 2 the BMPs were represented by modifying the SWAT parameters to reflect the effect the practices have on the processes simulated within SWAT (Bracmort *et al.*, 2006). In scenario 1, the vegetative filter strips with the appropriate model parameters: drainage area to VFS area ratio (DAFSratio), fraction of field drained by the most heavily loaded 10% of the VFS (DFcon), and fraction of flow through the most concentrated 10% of the VFS that is fully channelized (CF_{frac}) were modified. The effect filter strips is to reduce sediment, dissolved contaminants and sediment adsorbed organics in runoff (Tuppad *et al*., 2010). For this study the values 50, 0.5, and 0 were used for $DAFS_{ratio}$, DF_{con} and CF_{frac} respectively as recommended in conservation practice modeling guides for SWAT and APEX (Waider *et al*., 2009). The VFS simulation was applied on the CRDY for all soil types and for all range of slope classes. In scenario 2, appropriate parameters for representing the effect of stone/soil bunds are the Curve Number (CN2), average slope length (SLSUBBSN) and the USLE_P support practice factor (USLE_P).The SWAT assigned value of the USLE_P value of 1.0 is used prior to the application of BMPs. The modified value/Post-BMP value for USLE_P of 0.5 was assigned based on (Hurni, 1985) being the P factor recommended for all types of bunds in Ethiopia. The average slope length (SLSUBBSN) of 17.5m and 11m were taken for slopes 0-10% and 10-20% respectively from (MoARD, 2005). The minimum acceptable SLSUBBSN value of 10m by the SWAT was assigned for slopes greater than 20%. In scenario 3, the reforestation effect was simulated by replacing 5% of CRDY area by FOEB. The reforestation has the function of reducing over land flow and rainfall erosivity.

Climate change scenario

The monthly average values of 2m surface air temperature and total precipitation for baseline period i.e. present day climate under the 20th century experiment (20C3M) of 1971 – 2000 and the future periods 2011 – 2040 were downloaded from the World Data Center for Climate, Hamburg (cera-www.dkrz.de). Two models the CGCM3 and ECHAM5, and the two Special Report on Emissions Scenarios (SRES) scenarios, A2 and B1were used in this study. The A2 scenario features prominent fossil fuel usage by developing countries and slow development of alternative fuel technologies by developed nations. The B1 scenario illustrates a world relying on resource conservation and environmental sustainability. Since GCM data is too coarse for hydrological studies, a simple downscaling method called, delta method (change factor) was applied. The GCM data corresponding to the grid box closest to the study area was extracted and bi-linearly interpolated to Jimma station located in the catchment and then the delta method was applied to construct future temperature and precipitation series. Applying the delta change method assumes that GCMs more reliably simulate relative changes rather than absolute values (Hay *et al*., 2000). Delta change method is the difference between the future and the present day estimates (Raghavan *et al*., 2012). For this study, changes are the difference between future climate projections 2011 – 2040 and the 1971 – 2000(20th century experiment-20C3M) baseline current climate simulations. These changes were used to modify the observed time series of temperature and precipitation. Temperature was modified by the absolute difference between the monthly future and simulated climate, where as precipitation was modified by the relative difference between the monthly future and actual simulated by the GCM. Table 1 and Table 2 show the changes of temperature and rainfall as obtained by delta change method.

RESULTS AND DISCUSSION

Model calibration and validation

The SWAT flow prediction were calibrated against monthly average flows from 1980 – 1992 and validated from 1993 – 2000 at Asendabo gauging station, as shown in Fig.2 and Fig.3.The simulated flow matched the observed values for calibration period with NS and R^2 equal to 0.707 and 0.775. For validation period, the observed and simulated values showed acceptable agreement as indicated by NS and R2 values equal to 0.707and 0.767respectively. The P-factor and R-factor for the calibration was found to be 0.61 and 0.56 respectively. Table 3 shows the sensitive parameters and their fitted values.

Scenario analysis under current (1981-2000) and Future climate (2011-2040) condition

Under current climate condition of the control period of the1981 – 2000, the efficiency of BMPs in reducing the mean annual sediment flux at the outlet of Gilgel Gibe 1 Basin was determined. Accordingly, the reduction efficiencies with respect to scenario 0 were found to be 55%, 47.9% and 43 % for stone/soil bunds, VFS and reforestation scenarios respectively. However, the performance efficiencies of these BMPs were reduced in varying extent due to the predicted climate change of the future period of 2011 – 2040(2020s). Fig. 4 shows the efficiency of VFSs under current and future climate change. The effectiveness of VFS scenarios in the future climate condition is predicted to reduce in the range of 4.5% - 8.5%. The maximum reduction in efficiency is predicted by ECHAM5 model under A2 scenarios. This may be due to the maximum sediment flux predicted by the model under A2 scenario. Fig. 5 shows the efficiency of stone/soil bunds in reducing sediment flux at the outlet of Gilgel Gibe 1 basin under current and future climate change of the 2020s. Under the future climate change, the effectiveness of stone/soil bund scenario is reduced within the range of 4.5% - 6.8%. For scenario 3, Fig. 6 shows the reforestation efficiency. The efficiency under reforestation scenario is reduced in the range of 0.6% - 3.9%. From these results, we can conclude that the efficiency of reforestation scenario is least affected by the future climate change, while the VFS scenario in the most affected one. Although the reforestation scenario is less affected, its reduction efficiency is less than the efficiency of SSB. In addition, replacing 5 % of the CRDY into FOEB is challenging as we need to convince the farmers to change their crop land to forest land. It is also difficult to have the 5% change at once as it is made for purpose of simulation. In general, the efficiency of stone/soil bund is the most efficient in reducing the sediment flux under both current and future climate change as compared to the VFS and reforestation scenarios.

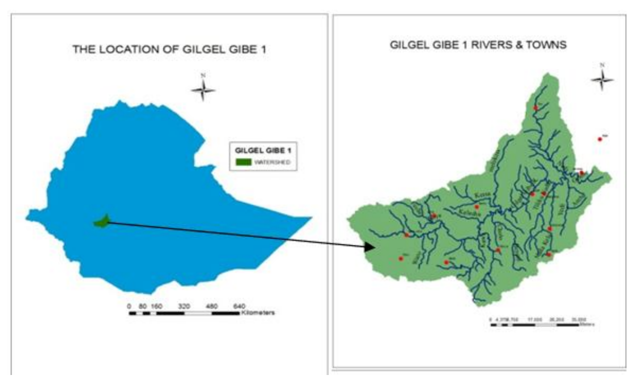


Fig.1. Location map of Gilgel Gibe 1

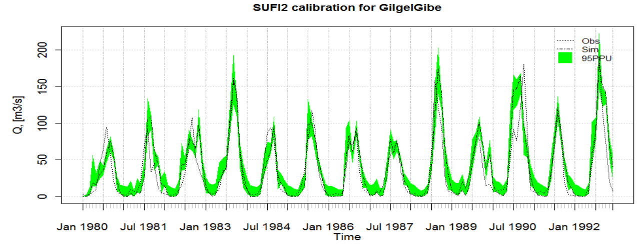


Fig.2. Monthly discharge calibration

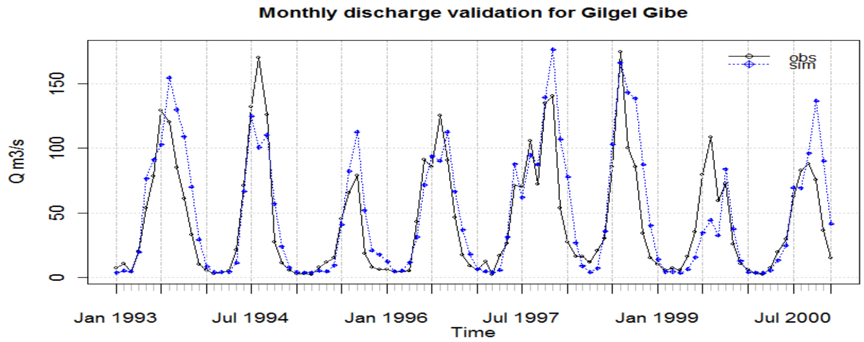
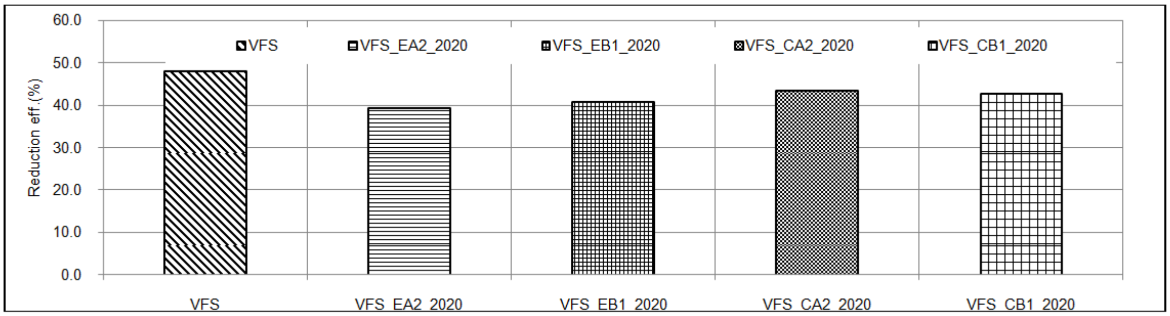
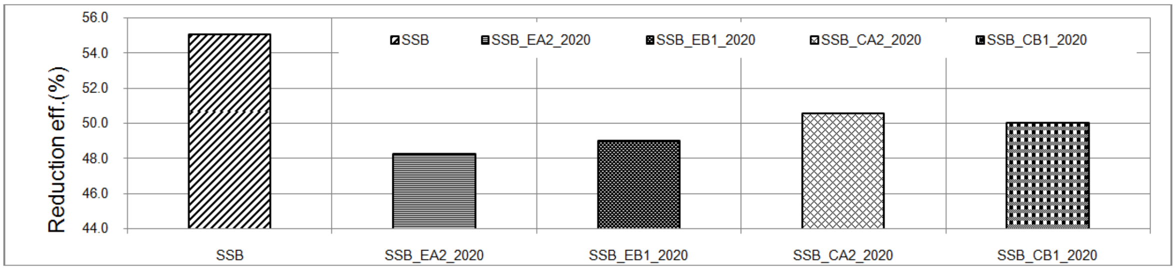


Fig.3. Monthly discharge validation



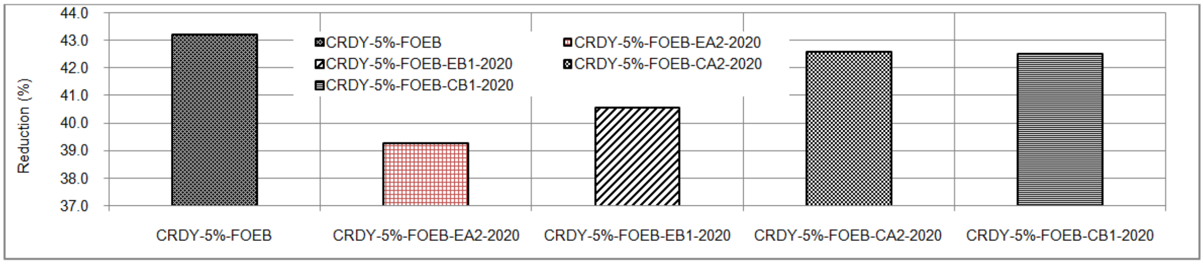
VFS stands for the efficiency of VFS under control period. VFS_EA2_2020 stands for the efficiency of VFS under future climate change as predicted by ECHAM5 model, scenario A2.similarly in VFS_CA2_2020, CA2 stands for the CGCM3 model under scenario A2 and CB1 CGCM3 scenario B1.

Fig.4. efficiency of VFS in reducing sediment flux with respect to scenario 0



SSB stands for stone/soil bunds, EA2, EB1 stands for ECHAM5 under A2 and B1scenario, and similarly CA2 and CB1 stands for CGCM3 model under A2 and B1 scenario.

Fig.5. efficiency of Stone/Soil bunds (SSB) scenario with respect to scenario 0



CRDY-5%-FOEB stands for the replacement of CRDY by 5% FOEB, and CRDY-5%-FOEB-EA2-2020 and CRDY-5%-FOEB-EB1-2020 is the efficiency of reforestation scenario under future climate change as predicted by the ECHAM5 model under A2 and B1 scenario, and similarly CRDY-5%-FOEB-CA2-2020 and CRDY-5%-FOEB-CB1-2020 stands for the efficiency of reforestation scenario under future climate change as predicted by the CGCM3 model under A2 and B1 scenario.

Fig.6 efficiency of reforestation scenario with respect to scenario 0

Conclusion and recommendation

This study evaluated the efficiency of BMPs under current and future climate change. This modeling approach is useful for decision makers and watershed development planners to identify the most effective BMPs under current and future climate conditions. This approach could be applied to investigate the efficiency of BMPs over the whole Omo-Gibe Basin where a cascade of hydropower projects are planned to be implemented. The result indicates that the climate change in the future period of the 2020s will reduce the efficiency of BMPs to varying extent. There is a significant change in the mean of the sediment reduced in the future climate condition for VFS and SSB. However, it is important to note that the BMPs will significantly reduce the sediment flux both under current and future climate changes and could increase the life span of the reservoir. Hence, the watershed development which has been under implementation should be strengthened. The efficiency of other BMPs for implementation shall also be investigated and the investigating should also be made based on the observed data to have reliable results.

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