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Evaluation of Management Practices for Sustainability of Water Resources in Arror River Watershed, Kenya

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Abstract

Water is an indispensable natural resource that is critical for sustaining life and ensuring healthy ecosystems. Since it is dynamic in nature with an ever-increasing demand, its sustainable use requires an integrated management approach. Impacts of water scarcity such as health problems, limiting economic and agricultural development and stress on ecosystems needs water resources to be managed sustainably. To understand this phenomenon, the study conducted sought to evaluate the various management practices for sustainable watershed and water resource management in Arror River watershed, Elgeyo Marakwet County. The primary data source was were remotely sensed data and socio-economic data while climate, river discharge and soil data formed the secondary data. Field surveys and questionnaires were used to collect information about indigenous and contemporary watershed management and conservation practices. GIS information was integrated with the Water Evaluation and Planning (WEAP) system and the Soil and Water Assessment Tool (SWAT, to analyse the various management practices in the watershed. The results from the field survey showed that the local communities in Arror river watershed had their traditional ways of managing water catchments with most respondents (89%) reporting the prohibition of cutting trees. They also reported some modern watershed management methods with agroforestry being the most popular (67.5%). Various scenarios were explored in both SWAT and WEAP models. The results from the SWAT model on the application of terracing and contour planting revealed a decrease in the annual mean flow of 15.4% and 24.1%, respectively while a combination of both revealed a reduction of 19.04%. The WEAP model scenarios revealed that the minimum 'flow requirement' scenario would yield the highest mean annual flows (85,113,000 m3 p.a) while the 'irrigated agriculture increased' scenario would yield the lowest mean annual flows over the 28 years (2013-2040). The 'irrigated agriculture increased' scenario posted the highest mean annual demand and the highest mean annual unmet demand. The 'dam construction' scenario revealed no unmet demand. The management practices that would enhance the sustainable management of the watershed include: contour farming, construction of a reservoir, maintenance of minimum environmental flows in the river, agroforestry and afforestation which are then recommended for Arror River watershed. Water managers and all stakeholders should understand how different drivers of change affect hydrology and therefore affect the related water demands and functions by the inhabitants in the basin so as to make informed decisions on the sustainable management of the watershed. The findings of this study are therefore intended to contribute towards sustainable watershed management.

Keywords: Minimum Flow Requirement, Contour Farming, Terraces WEAP, SWAT, GIS, Scenarios, Dam

INTRODUCTION

Water is life and without it life will be unbearable and eventually cease to exist (Viala, 2008). It is a major and common natural resource that is crucial for sustainable development and the well-being of mankind and other living organisms. The earth's water is constantly in motion, changing from one state to another which makes its planning and management complex and difficult under the best of conditions (Turner, 2004; Bressers & Lulofs, 2010; Kirschke & Newig, 2021). However, the availability and use of the water resource is mainly constrained by its spatial quantity and quality distribution. Water resource quantity degradation is a serious national and international problem that affects economic productivity and the environment in multifaceted ways globally, causing widespread health problems, and harming a wide range of ecosystems (WWAP, 2012). Current water management practices are still focused on reacting to events that occurred in the past; the reactive approach instead of a more strategic oriented water management, the proactive approach (Loon & Droogers, 2006). Water resources touch every sector of the economy and therefore it is important to improve its management in order to reduce the degradation and enhance equitable access and utilization, thus reducing and alleviating sources of water conflict as observed by Mwiturubani & Wyk (2010).

The rationale for the sustainable development and management of freshwater resources is clearly articulated in the sustainable development goals (Griggs et al., 2013). Similarly, vision 2030 also advocates for more efficient management of Kenya's scarce water resources, for household and commercial enterprises, in order to achieve the economic, social and political priority projects suggested (Republic of Kenya, 2007). To stop the unsustainable exploitation of water resources there is need to initiate water management strategies at the regional, national and local levels, which will consequently promote both equitable access and adequate supplies (Lead et al*.,* 2005). This approach includes the development of alternative water resources; protection of water resources to stabilize and improve its quality and quantity; and demand management implemented at the level of each river basin (Savenije & Van der Zaag, 2008). As observed by Westphal et al., (2003) a river basin-level perspective enables integration of downstream and upstream issues, quantity and quality, surface water and groundwater, and land use and water resources in a practical manner. Moreover, attention to management of watersheds is increasing across the developing world as soil erosion continues to degrade agricultural land, while dams, reservoirs and irrigation infrastructure continue to be clogged with sediment (Abdelsalam, 2008).

Meanwhile, most of the projected global population increase takes place in third world countries that already suffer from water, food, and health problems (Oki & Kanae, 2006; Boretti & Rosa, 2019). In Africa, a third of the continent's population, 300 million people were already experiencing water scarcity in 2010 as affirmed by Braune & Xu (2010). Currently, one-third of the people living in Africa are facing water scarcity while around 400 million people in sub-Saharan Africa lack access to drinking water (Mason et al., 2019). It is further projected that half of the African countries will suffer water stress by the year 2025 (Mwiturubani & Wyk, 2010). The fundamental issue facing water resources in Africa do not appear to be one of water availability only, but also of human factors (Biswas & Tortajada, 2019; Tzanakakis et al., 2020). These factors are related to the governance of the available water resources, legislative and institutional frameworks, overexploitation and pollution of the resources, conflict and political instability, inadequate technical know-how and institutional capacity, as well as low priority given to water in terms of human resources and budgetary allocations (Beekman & Pietersen, 2007).

The dominant water resources management challenge is how to secure water to cover food demands accelerated by a rapidly expanding world population, while at the same time sustaining other critical ecological functions in regions with highly unreliable and scarce water resources (Bhatt, 2006; Dehghanipour et al., 2020). This is more pronounced in the developing countries where 95% of the world's population growth occurs, and predominantly in the Sub-Saharan Africa, which host the largest share of water scarcity-prone areas (Rockstrom, 2003; Balogun & Etop, 2013). In the current state of rapid urbanization in majority of the third world countries, excessive consumption in developed nations, and political tensions worldwide, one of the major limiting factors on future development is freshwater availability (Hinrichsen, & Tacio, 2002; Chellaney, 2013). As the disparity between the rich and the poor widens, so does the provision of services to cover their basic needs (Kahl, 2006). The shortages of fresh water can have a massive effect upon a society, ranging from food supplies to industry, spread of disease and damage to natural systems (Hinrichsen, & Tacio, 2002; Tarrass & Benjelloun, 2012).

On the Kenyan scene, water scarcity has caused economic decline and rampant food insecurity and has become a basis for conflicts in rural Kenya that tend to be resource-based with a bias towards shared water sources (Cheserek, 2007; Lelo et al., 2005; Kanyua, 2020). Water resources underpin the country's main economic sectors: agriculture, livestock, tourism, manufacturing and energy. The social, economic and environmental aspects of water signify its importance in the country's sustainable development, attainment of Vision 2030 targets and realization of human rights. This is further reinforced by Kenya Institute for Public Policy Research and Analysis (KIPPRA) (2013) which asserts that prudent management of water is essential in minimizing resource-use conflicts within the country and with other countries sharing water resources.

Kenya's renewable freshwater resources are estimated at 20.2 km^3 per year, which corresponds to 647 m^3 per capita, one of the lowest in Africa and the situation is expected to get worse due to population growth and climate change (Republic of Kenya, 2002c). Roughly a third of its population have no access to safe water supplies and nearly 50% live below the absolute poverty line, while the national economy and environment are struggling with the negative effects of deforestation, poor land management, and water shortages (Mogaka, 2006). It is important to note that water scarcity has reached critical levels and dire consequences are already being felt in different sectors as is the case of some hydroelectric power (HEP) generation stations facing closure due to low water levels, for example Masinga dam (Bunyasi et al., 2013). Access to clean water is already a problem in many areas of the country, including the capital city, Nairobi and other large towns (Marshall, 2011). The most vulnerable are the rural poor who depend on agriculture and livestock for their livelihood and are often affected by the recurrent droughts which lead to escalated poverty and food insecurity (Kandji et al., 2006).

River Arror watershed manifests strong signs of human induced land degradation due to high pressure on soil and water resources, where land use/ land cover changes upstream are affecting the ecological and hydrologic balances of the river downstream (Muchemi, 2004; Muli, 2007; Chebet et al., 2017). A pressing need therefore exists to develop environmentally sustainable and socially equitable approaches to water development and management that balance the needs of the environment, with economic growth, while addressing wide-spread poverty and lack of basic water as well as elimination of the water related disasters (Soussan et al., 2006). It is against this background that this study sought to evaluate the potential water resources management practices with a view of proposing the best management practices that would promote sustainability in Arror river watershed. This was done by simulating and describing the impacts of some water resources management practices on watershed response using the Soil and Water Assessment Tool (SWAT) and Water Evaluation and Planning W EAP models.

MATERIALS AND METHODS

Study Area

The study area comprises the regions draining water into the Arror River, a tributary of the Kerio River. The river rises in the eastern part of Cherangani Hills, the bulk of the catchment being in the Embobut and Kipkunur forests, at altitudes between 3,200 and 2,300 m above sea level (Kerio Valley Development Agency [KVDA], 1989). The watershed is in Elgeyo Marakwet County, Kenya. The river flows through three administrative divisions of Marakwet East and West, the sub-counties of Kapyeko, Kapsowar and Tunyo, and extends from latitude 0^0 51’ to 1^0 19’ North, and longitude 35^0 26’ to 35^0 38’ East (Figure 1). The watershed covers approximately 285 km^2 and is the largest of those draining to the Kerio valley. The river is perennial and approximately 112 km long, and is the main tributary of the larger Kerio River, which feeds Lake Turkana, the world’s largest permanent desert lake (Muli, 2007). The catchment was sub-divided into three sub-catchments based on the main tributaries. The three sub-catchments were then named as the upper, middle and lower sub-catchments covering 76.15 km^2, 92.9 km^2 and 117.27 km^2, respectively. The annual mean temperatures in the watershed vary with the altitude and range from 18ºC to 22ºC on the highland, and from 25ºC to 28ºC in the valley. The average annual rainfall in the watershed also vary with the altitude and ranges from 700 mm in the semi-arid Kerio valley to 1700 mm on the Marakwet highlands (Cherangani Hills) (County Government of Elgeyo Marakwet, 2018).

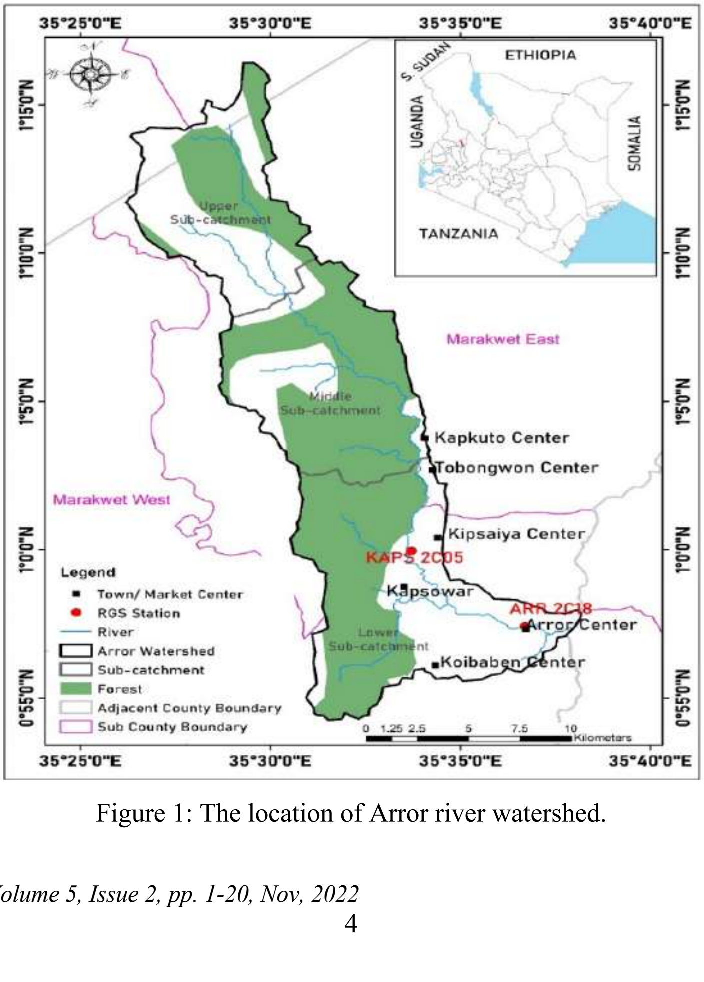

Figure 1: The location of Arror river watershed.

Methods

The study used the Soil and Water Assessment Tool (SWAT) and the Water Evaluation and Planning (WEAP) system to evaluate the watershed management practices for the sustainability of water resources in Arror watershed. The primary data sources used include the socio-economic data which were obtained through household surveys and key informant interviews; Landsat satellite images and a Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) downloaded from United States Geological Survey (USGS) Global Visualization Viewer (GloVis) (https://earthexplorer.usgs.gov/); while the secondary data include climate, soil, River discharge and population.

Sampling and Collection of Socio-Economic Data

The target population comprised the residents of the Arror watershed, approximately 10,000 people. Multi-staged cluster sampling was used to select random targets and the appropriate sample size was determined using the formula (Equation 1) published by Fisher et al. (1991).

$$n = Deff * \frac{Z_{\frac{\alpha}{2}} * P(1-q)}{d^2} \tag{1}$$

Significance level (α) = 95% and Z $_{\alpha/2}$ *= 1.96*

Based on the formula, the sample size for the watershed was 646 households.

The main data collection tool for surveys in the study were questionnaires. Respondents had to be aged 18 years or more and genuine residents of the region. Discussions were also held with key professionals – the county Forest Officer, Agricultural extension officers, Water Resource Management Authority (WRMA) officers, and County environmental officers. Field surveys and questionnaires were administered to collect information on the indigenous and contemporary watershed/water resources management practices in Arror watershed.

Land Use Land Cover Analysis

Landsat 5 thematic mapper (for January 1986) and Landsat 7 enhanced thematic mapper (for January 2000 and 2012) with 30 m resolution were used to analyze land use/cover in the catchment. The land use classification system published by Anderson et al. (1976) was modified for the study and eight classes were considered: Coniferous forest cover, Deciduous forest cover, Grassland, Bare ground, Riverine and ridge vegetation, Crop land and Wetlands. The results of the land use analysis (Chebet et al., 2017) were used as inputs for the SWAT and WEAP models.

Climate Data

The climate data were sourced from the Kenya Meteorological Department (KMD) which is the official custodian of climatic data in Kenya. The KMD data was complemented with data collected by the Kerio Valley Development Authority (KVDA). Climate data for the Arror watershed were limited because there is no well-maintained meteorological station. The stations at Kapsowar and Arror, within the study area, collect only rainfall data with numerous gaps.

Due to inadequate data availability, satellite data were used for analysis in this study while the observed data from KMD and KVDA were used for validation. The rainfall data from Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) with a spatial resolution of 0.05° × 0.05° ≈ 5 km was used (https://www.chc.ucsb.edu/data). The temperature data used was from European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) at a spatial resolution of 0.25° x 0.25° ≈ 31 km (https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5). The observed data from Eldoret, Kitale, Kapsowar Inland Mission, Chebiemit, and Kapcherop stations were used to validate the satellite data.

ArcSWAT 2012 Model Set-up

The SWAT model was developed using the DEM, land use/cover map, and soil and climate data, to create sub-basins and, subsequently, the hydrologic response units (HRUs). Soil data was obtained from Kenya Soil Survey (KSS). The ArcSWAT 2012 model simulation was set up using a two-year warm up period (1985 and 1986).

The model was calibrated using observed annual discharge data from gauging station 2C18 (at the catchment outlet) obtained from Kerio Valley Authority (KVDA). The initial 15 years (1985-1999) were used for calibration and the rest (2000-2012) for validation. Manual calibration was done using actual discharge data, to fine tune the model. The aim was to make the simulated outflow close to the observed outflow; this was to be achieved by adjusting values of surface runoff and base flow contribution to the reach with reference to the land cover values (Chebet et al., 2017). The portion of land occupied by agricultural activities was of key importance in calibration, parameters representing soil and moisture conditions required for crop growth were adjusted (Arnold et al., 2012). After each calibration run, the observed and simulated flows were compared at annual time steps for the first 15 years. The values of R^2 and NSE were then checked to assess the model's performance (Moriasi et al., 2012). Every calibration run was followed by validation. The results for the R^2 was 0.81 for both calibration and validation while for the NSE were 0.86 and 0.82, respectively. The model was therefore not perfect but could provide a good estimate.

The SWAT model was used to evaluate the impact of terracing and contour farming on water quantity. Terracing and contour planting were identified as probable measures in agricultural areas characterized by slopes. In the model, the two conservation measures (terracing and contour farming) were introduced in the simulation and the purpose was to reduce runoff and the effects of erosion. This was done by assessing their impact on the water flows out of the catchment for the year 2012.

Terracing scenario was simulated in SWAT by adjusting both erosion and runoff parameters. The USLE practice (TERR_P) factor, the slope factor (TERR_SL) and curve number (TERR_CN) were adjusted to simulate the effect of terracing by providing values that would fit the particular soil properties and land slope. It was important to note that TERR_SL was set to a maximum of the distance between two terraces. Contour planting scenario was simulated in SWAT by altering curve number (CONT_CN) to account for increased surface storage and infiltration and the USLE Practice factor to account for decrease in erosion. The two were applied to slopes between 2% and 10%.

A combined application of both terracing and contour planting was simulated to see the overall impact. It was done on a 50/50 ratio, which means half of the agricultural land on slope had terracing while the other half had contour planting.

Setting Up the WEAP Model

The WEAP model was used to evaluate the future water demands in the Arror watershed region. The WEAP tool is one of the components of Integrated Water Management Support Methodologies (IWMSM) that can be implemented relatively easily to evaluate scenarios on different water allocation strategies in a user-friendly environment (SEI, 2005; SEI, 2015). The data required for the WEAP model consists of the water demand sites, and catchment state (land use, climate and soil conditions). The WEAP model makes it possible to integrate all these variables and hence make informed decisions on the planning and management of the water resource in a watershed (SEI, 2015). Arror River was considered as the main source of water supply in the watershed.

Land use: The land uses in the watershed evaluated in GIS were incorporated in the WEAP system. The percentage area covered by each land use were considered and for agriculture the principal crop in the watershed was chosen as the representative crop for the area for the purpose of analysis. The Kcs for each of the three catchments were calculated with the help of the guidelines in FAO-56 paper (Allen et al. 1998; Chebet et al., 2019) where the dominant land uses were considered. The Kc of the dominant crops which were potatoes, maize and millet for the upper, middle and lower sub-catchments, respectively, were obtained from Puttemans et al. (2004). The effective precipitation which is the percentage of precipitation available for evaporation was calculated based on the total monthly precipitation.

Climate data: The monthly rainfall data for 1986 - 2012 (27 years) were utilized. Since the evaporation data for the study area were not available, ETo calculator was used to obtain the reference evapotranspiration (ETo) of the catchment (Allen et al., 1998). The ETo calculator computes ETo from meteorological data by means of the FAO Penman-Monteith equations. In this study the monthly maximum and minimum temperature data was used to compute ETo.

Catchment: On catchments in the WEAP model, the study utilized the Rainfall Runoff method which is a simple method that computes runoff as the difference between rainfall and a plant's evapotranspiration. The evapotranspiration is estimated by the reference evapotranspiration (ETo) and the crop coefficients (Kc) for each type of land use. Then crop water requirement (ETc) for a specified period is computed as the product of Kc and ETo to reflect differences occurring from plant to plant (Allen et al., 2005).

Water demand Sites: Domestic, agriculture, and livestock are three main uses of water in the study area and these were considered as demand sites. The other demand areas such as commercial, institutional and industrial were not included in this analysis. Water use activities and rates for all the demand areas identified were then developed. The human population of the study area was used as the annual activity for domestic use. The population census reports of 1979, 1989, 1999 and 2009 were used for the purpose of estimating the annual activity of the three catchments (Republic of Kenya [ROK] 2010a). The annual use rate was assumed as 25 litres per head per day (Republic of Kenya [ROK] 1984). For livestock, the annual activity is the total number of livestock in the area. The animals kept in the study area were mainly cattle, goats, sheep and donkeys. The total number of livestock was obtained from the census reports. The livestock demand was assumed as 75 litres per day per livestock unit (LSU). LSU can be one grade cattle or three native cattle or fifteen sheep (Republic of Kenya [ROK] 1984). On agriculture use, the data on the quantity of water used for irrigation was estimated using the computed ETc and effective precipitation (P) concept as outlined in FAO-56 (Allen et al. 1998). The total size of land under cultivation obtained through interviews of the residents and from the census reports was considered as the Agricultural annual activity.

Reserve Requirements: Based on the Kenya Water Act (2016) whose key principles are sustainability and equity and emphasizes that, as water resources are being utilized for social and economic development, it is critical to protect the environment while ensuring that the water needs of present and future generations can be met. To achieve this, some water should be retained in the river to maintain its ecological functioning. Reserve requirement (minimum flow) is defined as a single threshold beyond which water cannot be abstracted for consumptive use, and often provides sub-optimal habitat conditions for aquatic species (McEvoy et al., 2018). This water is also referred to as a flow requirement and must be met before water is allocated to other demand sites.

Calibration and Validation of the WEAP Model: After setting up the WEAP model, calibration had to be undertaken before exploring the various scenarios. Calibration was done by comparing WEAP simulated and the observed river discharge data. Model calibration was then followed by validation in order to assess the performance of the model. The model performance was evaluated using standard statistics; mean error (ME), mean square error (MSE) and model coefficient of efficiency (EF) also known as NSE and R^2 (Moriasi et al., 2012). The validation results were ME (-0.00), MSE (0.03), EF (O.85) and R2 (0.88), while the calibration results were ME (0.06), MSE (0.03), EF (O.95) and R2 (0.96). The results are within the acceptable thresholds and thus indicate that the model is good and can be used to simulate the study area.

Scenarios: Several scenarios were considered in the study; the Reference (business as usual), change in population growth patterns, ecosystem requirements tightened, increased cultivated/irrigated areas and reservoirs constructed scenarios. The water allocations, demand, unmet demands and demand coverage for the various water uses were then compared for the different scenarios. Figure 2 shows the location of the reservoir that was used to simulate the impact of reservoir construction on water demand in the watershed.

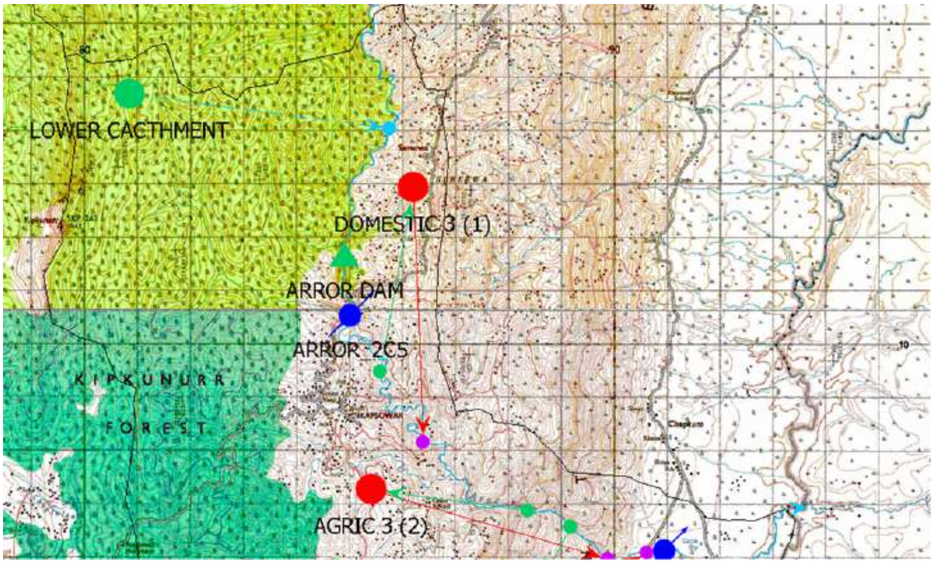

Figure 2: Proposed location of the dam used to assess the impact of the construction of a reservoir in the watershed.

RESULTS

Traditional and Contemporary Watershed Management and Conservation Practices in the Study Area

The results on the traditional and contemporary watershed management and conservation practices in the study area showed that the local communities in Arror watershed had traditional ways of managing their water catchment areas. On the traditional methods of watershed management practiced by the community, approximately 89% of the respondents reported the prohibition of cutting trees; 71% reported that cultivation on river banks was prohibited while 68% reported that clans were responsible for the management of forests in the area (Table 1). According to the respondents, each clan was assigned a forest in their jurisdiction to take care of and they were supposed to guard it against any intruder from other clans. They were also in charge of the enforcement of the laws that governed forest protection and conservation. There were also taboos that were used to protect the forests and watersheds in the region for example; some areas of the forest were out of bounds, and the use of some trees as firewood was prohibited among others.

Table 1: Traditional water resource and watershed management practices

Indicators	Number of times mentioned	Percentage
Cutting of trees prohibited	525	88.8
Felling of trees for firewood prohibited	524	88.7
Cultivation of riverbanks prohibited	420	70.7
Clan management of forests	402	67.7
Water Catchment areas out of bounds	397	67.2
Other clans were not allowed to enter forests	363	61.1
Communal irrigation furrows developed	76	12.8

**Percentages do not add to 100% because respondents mentioned more than one concern.*

Apart from the traditional water resource and watershed management practices mentioned above the respondents also reported the application of some of the modern management methods. Agro-forestry (67.5%) was the most popular method followed by terracing (48.8%), rainwater harvesting (24.4%), mulching (20.4%), contour farming (4.8%), and destocking (3.3%) in that order. It was also noticed that most residents had not embraced destocking and contour farming as some of the methods that could enhance watershed management.

The Impact of Soil Conservation Measures on Arror River Discharge

The effect of some of the contemporary watershed management practices were evaluated in SWAT and results are as shown on Table 2 and Figure 3.

Table 2: Comparison of annual mean discharge for the three scenarios

Scenario	Mean Annual discharge m^3/s	% reduction	Total annual discharge m^3/s
Actual	2.34	-	28.08
Terracing	1.98	15.4	23.76
Contour planting	1.77	24.1	21.28
Combined	1.90	19.04	22.73

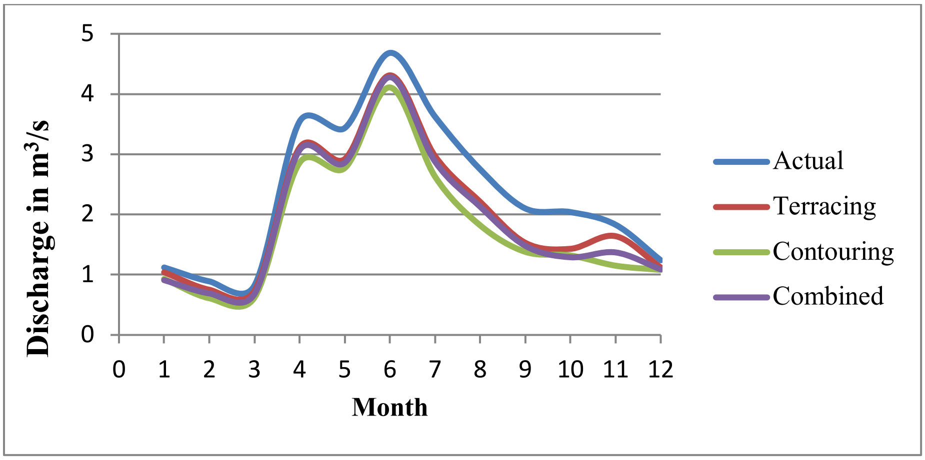

Figure 3: The stream flows of some management practices.

The impact of contour planting, terracing and combined terracing and contour planting revealed a decrease of the annual mean flow by 15.4%, 24.1%, and 19.04%, respectively (Table 2). The minimum flows for actual, terracing, contouring and combined were 0.82 m^3/s, 0.73 m^3/s, 0.61 m^3/s and 0.68 m^3/s, respectively. The maximum flows were 4.68 m^3/s, 4.31 m^3/s, 4.11 m^3/s and 4.28 m^3/s in the same order (Figure 3).

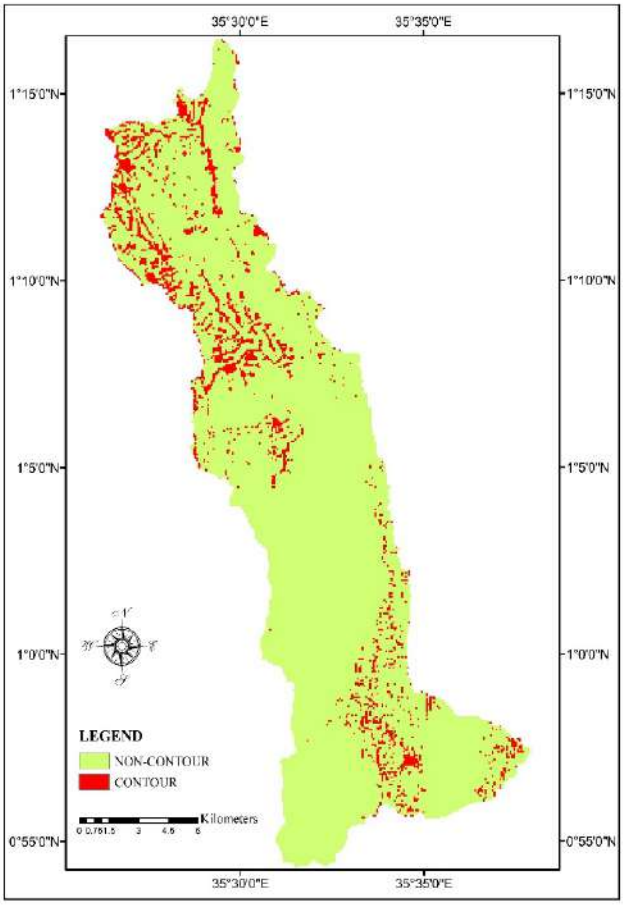

Figure 4: Areas suitable for contour farming.

A suitability analysis was performed in ArcGIS to determine the areas that are suitable for contour farming in the watershed (Figure 4). These are the areas that are between 2% and 10% slope and are under crop land. The rest of the areas are either too steep for cultivation or have a slope that is less than 2% and thus do not require any conservation measure or are covered by another land use other than cropland.

The impacts of the various scenarios on river flows, water supply and demand in the WEAP model

In order to evaluate the effectiveness of various management practices for Arror river watershed, WEAP was used to explore the impacts of a number of scenarios on river flows; and water supply and demand. All these scenarios together with the simulations in SWAT were used to come up with some of the measures that can be put in place to enhance the sustainable management of the Arror River watershed.

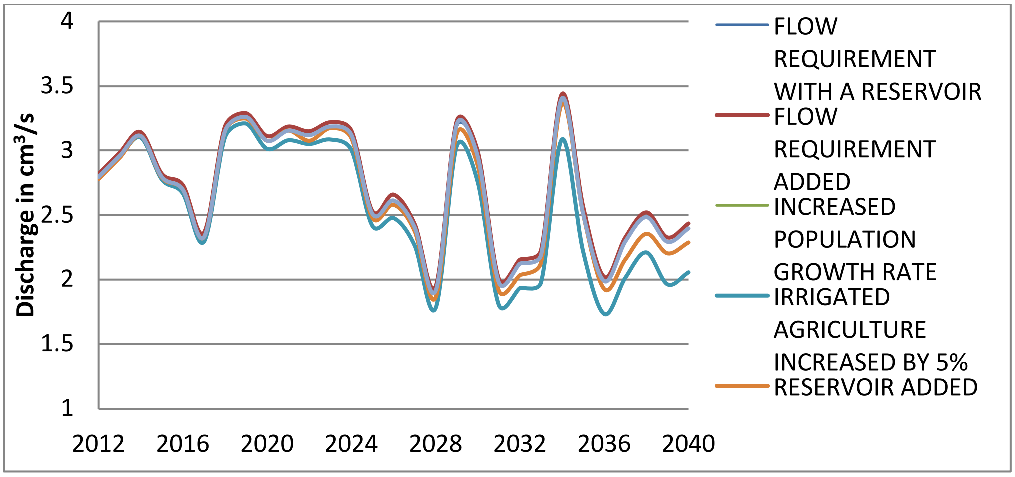

Figure 5: The mean annual flows for the eight scenarios (WEAP) for 2012-2040.

Figure 5 shows that the 'flow requirement' scenario yieded the highest mean annual flows while the 'irrigated agriculture increased by 5%' yielded the lowest mean annual flows over the 28 years.

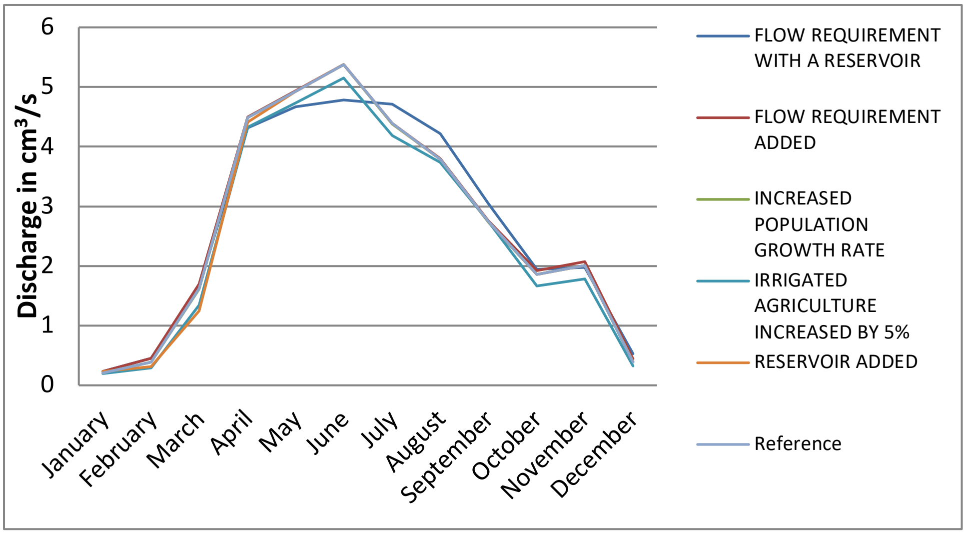

Figure 6: Mean monthly flows for all the scenarios 2013-2040.

The mean monthly discharge for all the scenarios simulated in the study shows that the peak of the river flows is in June with January, February and December yielding the lowest amounts. The 'flow requirement added' scenario had the highest average flows from January to July but was overtaken by the 'flow requirement with a reservoir' scenario in the remaining months of the year. This can be explained by the fact that the area experiences low rainfall in the earlier part of the year and therefore without the flow requirement introduced there will be less water retained in the river since it is scarce. The lowest average monthly flows were recorded by the 'irrigated agriculture increased by 5%' scenario during all the 12 months. The 'reservoir added' scenario has its average monthly flows being less than reference scenario from January to October and equal to the 'reference' scenario from November to December thus reduced flows in most part of the year. The 'increased population growth rate' scenario yielded the same average monthly flows with the 'reference' scenario. On minimum mean monthly flows, the 'flow requirement added' scenario, posted the highest amount and had a smooth peak as compared to the rest of the scenarios (Figure 6).

Table 3: The outcome of the various scenarios in WEAP (Mean annual in Million Cubic Metres)

Scenario	**River Flows**	**Supply**	**Annual Demand**	**Unmet Demand**
Reference	84.74	21.66	23.17	1.51
Increased irrigated agriculture (5%)	80.06	26.87	30.53	3.64
Increased population growth rate (3.5%)	84.72	21.78	23.29	1.51
Flow requirement	85.11	21.22	23.17	1.95
Reservoir Added	83.41	23.17	23.17	0.00

Table 3 shows a summary of the results of the major scenarios in WEAP. It is apparent that the 'increased irrigated agriculture' scenario posted the highest mean annual demand and the mean annual unmet demand. The second highest in terms of demand was the 'increased population growth rate' scenario. On the unmet demand the second highest was the 'flow requirement' scenario which ensures that there is a minimum amount of flows that should be retained in the river and hence reduces the quantity of water available for supply in the watershed leading to increased shortage and thus higher unmet demand. The 'dam construction' scenario shows that there will be no unmet demand and this is because the dam will be able to collect and store water during the high rainfall seasons and this water will be used during the dry season and thus minimize the shortages in the watershed.

To further evaluate the management practices, we simulated the impacts of the various scenarios on the water demand reliability (the percentage of the time steps in which a demand site's demand was fully satisfied) for all the demand sites. The three main demand sites were analysed in the three sub catchments, the upper sub catchment (Agric upper, Domestic upper and livestock upper), middle sub-catchment (agriculture, domestic and livestock) and the lower catchment (agric 3, domestic 3 and livestock 3) (Figure 7).

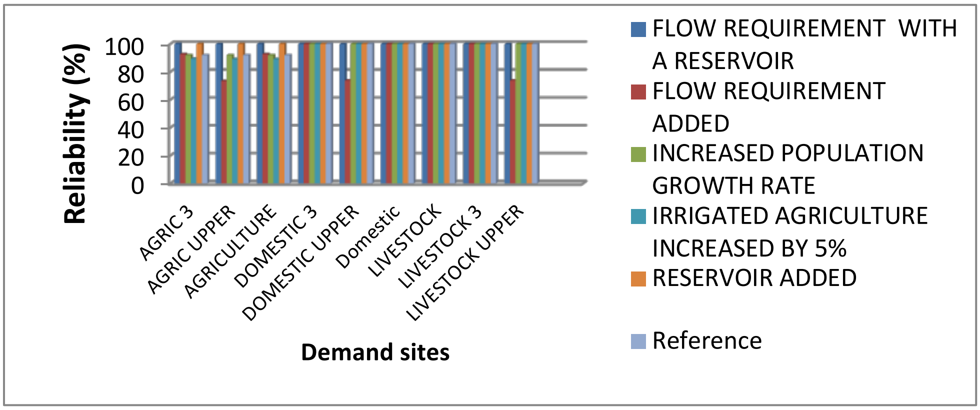

Figure 7: Demand reliability: 2013-2040.

The results on demand reliability indicated that all the domestic and livestock demand sites in the middle and lower sub-catchments were fully satisfied under all the scenarios over the 28 years (2013-2040). All the agriculture demand sites showed less than 100% under all the scenarios except for the 'reservoir added scenario'. The demand reliability in the 'reservoir added scenario' was 100% for all the demand sites for the entire period. This means that all the demand sites were fully satisfied under this scenario for the entire period. The 'flow requirement' added scenario on the other hand posted the lowest demand reliability for domestic and livestock demand site in the upper sub-catchment.

DISCUSSION

The Potential Watershed Management Practices for the Sustainability of Water Resources in Arror River Watershed

Based on the results of the simulations of the effects of some watershed management practices (i.e. contour planting and terracing) in the SWAT model, it was observed that application of contour farming yielded the highest run off reduction, followed by a combination of the two practices and the least was terracing. All the three scenarios yielded less runoff than the actual and this implies higher water infiltration in the catchment. The results therefore revealed that contour planting would be the best management practice to consider when farming on the slopes since it reduces the flow of water out of the catchment significantly. Contour farming involves tilling and planting across the slope, following the contour of the land, as opposed to farming up and down the hill. This creates small ridges that slow runoff water, and increases the rate of water infiltration, reduces surface runoff and the hazard of erosion (Spekken et al., 2016). It also promotes better water quality by controlling sedimentation and runoff and the increased rate of water infiltration leads to conservation of soil moisture. Stevens et al. (2009) also observed that contour farming reduces soil erosion compared to farming up and down hills. Similarly, FAO (1993) reported that contour farming limits soil loss to about 18 t /ha/year as compared to 46 t/ha/year when using conventional tillage. It is suitable for slopes between 3% and 8% according to FAO (1993) and hence suitable for the study area since most of the agricultural area has a slope of greater than 3%.

On the other hand, terracing involves the use of the topography of the land to slow water flow through a series of terraces (FAO, 1993). Terracing is the making or forming of a sloping land into a number of level flat areas resembling a series of steps. This manipulation of the water flow prevents it from gathering speed and washing soil away from farmlands and promotes absorption of water by the soil and thus saves soil from erosion (Wei et al., 2016). Another positive effect is the decrease in surface runoff, and increase in groundwater recharge (Winter et al., 2008). However, when the slope is steeper (>8%) terracing becomes expensive and less effective (UNDP, 1990; Foxhall, 2013; Chapagain & Raizada, 2017). In a nutshell, blue water flow and resources, in quantity and quality, are closely determined by the management practices of upstream land users.

The results further revealed that all the domestic and livestock demand sites in the middle and lower sub-catchments were fully satisfied under all the scenarios over the entire study period. Also, all the demand sites posted 100% reliability throughout the study period under the 'reservoir added scenario'. The 'flow requirement' added scenario on the other hand posted the lowest demand reliability for domestic and livestock demand site in the upper sub-catchment. This is because the minimum flow requirement was accorded the highest priority and so during the dry seasons the water was just enough to cover for the flow requirement and insufficient amounts were left for the other demands. The upper sub-catchment was highly affected because it had the highest livestock and human population. Therefore, there is need to improve the management of the catchment so that the water quantity will increase hence satisfying the minimum flow requirements and all the other water demands. The 'reservoir added' scenario is the only scenario without any unmet demands throughout the year and displays 100% coverage throughout the year on average. The 'flow requirement added' and 'flow requirement added with a reservoir' scenarios have unmet water demands in more than half of the year. This shows that if the environmental minimum flows are safeguarded in Arror River there will be increased shortage of water for the various uses in the watershed. There is a need therefore to improve the management of the catchment so as to increase the water resource availability in the area and thus boost the water supply. With proper management there will be enough water for the sustenance of the ecosystem, human use and all other organisms that depend on it.

The results further show that if irrigated agriculture is expanded in the watershed the average monthly flows would reduce substantially due to high evapotranspiration and more water abstractions from the river. Besides, the protection of environmental flows will enhance the river flows throughout the year and this will be boosted further by the construction of a dam. Flow requirement usually ensures that there is a minimum flow retained in the river for ecological purpose and is normally given the highest priority so that it is satisfied before any other demand. It therefore guarantees river flows even during the driest seasons of the year. This is one of the management practices that should be applied in Arror catchment so as to ensure ecological sustainability. According to previous studies (e.g. Acreman & Dunbar, 2004; Arthington et al., 2018), there is a growing demand worldwide to conserve or restore the ecological health and functioning of the rivers and their associated wetlands for the benefit of society and nature. It is widely recognized that any artificial variation to a river flow regime will alter the river ecosystem (Poff & Matthews, 2013). River managers need to be able to define the river environmental flow regime that will support the desired ecosystem and to quantify the ecological effects of alterations to the flow regime caused by artificial influences, such as abstractions and reservoir operations (Acreman & Dunbar, 2004; Acreman et al., 2014).

The results further show that if a reservoir of 100 million m^3 is constructed in the area the water shortages that occur during some months of the year will be addressed and all the demand sites will be satisfied throughout the year. In addition, the reservoir will be able to supply adequate water for irrigating up to 150% of the current agricultural area in the lower catchment. This will indeed boost food supply, promote economic development and hence improve livelihoods in the watershed. The reservoir will also be used to supply piped water to the households in the region and this will improve clean water accessibility in that currently the residents have to walk for an average of 2.5 km (County Government of Elgeyo Marakwet, 2013) to fetch water from rivers whose quality is not guaranteed. This is consistent with the findings of Biemans et al. (2011) who observed that the construction of reservoir improves water availability and supply.

As indicated by previous studies, the best watershed management practices should be those that are targeted at increasing productive transpiration, reducing soil surface evaporation, controlling runoff, reducing flood risk, encouraging infiltration and groundwater recharge (e.g. Singh et al., 2014; Asmamaw, 2017; Garg et al., 2021). In consonance with this, the results of our study show that the practices that can enhance sustainability in Arror watershed are the construction of a reservoir as enforcement of minimum flow requirement in Arror River as also proposed by Chebet et al. (2019. Additionally, the use of contour farming in agricultural lands, agro forestry, conservation of the forest cover, application of more efficient irrigation methods and keeping an optimum number of stock would also enhance the sustainability of the watershed. Contour ploughing prevents excessive soil loss as gullies are less likely to develop and also reduce run off (Spekken et al., 2016) and this increases the amount of water received by plants. The construction of a reservoir/dam across the river generally checks the speed of water and thus controls surface runoff, reduces flood risk and controls soil erosion by river floods. Moreover, the reservoir also helps in storing water during the high flows and hence enhance water supply in the area especially during the dry seasons (Biswas, 2012). The area under forests should be increased by afforestation and indiscriminate felling of trees should be stopped as more forest cover leads to low runoff and increased infiltration hence more water retained within the watershed in form of ground water (Ilstedt et al., 2007; Mongil-Manso et al., 2022). This in the long run will reduce droughts and floods among other disasters in the area.

To further enhance sustainable watershed management, overgrazing in forests and grasslands should be properly checked. Separate grazing grounds should be earmarked and fodder crops should be grown in large quantities to avoid free movement of animals in the fields as they loosen the soil by their hooves which lead to soil erosion. All these management practices if put in place will enhance water availability; reduce loss of fertile soil through erosion as well as siltation of the reservoirs. Water resource systems are directly and indirectly affected by the interaction of numerous human related drivers of economic, social, and demographic functions, including climate change as an uncertain driver (Davies & Simonovic, 2011; Cosgrove & Loucks, 2015). There is need therefore to integrate the traditional and the contemporary methods in the management of Arror watershed. The local institutions should be involved in the management and conservation of natural resources. The broader view through participatory management of watersheds is to capture dimensions and societal issues that are not normally included in land use planning and management. These include causes of natural resource degradation and related land use activities. The importance of management of watersheds is therefore to ensure that the use and modification of water resources, land based activities at catchments do not undermine the function of ecosystems and other resources. Participatory approach of water resource management is one of the principles of the Dublin convention which requires water development and management be based on involvement of all users, planners and policymakers at all levels. It further aims at managing the land and water resources in a manner that sustains adequate levels of water, soil and fibre production (Solanes & Gonzalez-Villarreal, 1999; Petit & Baron, 2009). To achieve proper management of the basin and its catchments, efforts are therefore required for regional coordination as well as planning at national and local levels. The stakeholders should be given opportunities to bring forward and jointly negotiate their interests, set priorities, evaluate opportunities, implement and monitor the outcomes.

CONCLUSION

This paper analysed the impacts of various watershed management practices with a view of proposing the best management practices for the sustainability of water resources in Arror watershed. The SWAT and WEAP models were used to simulate the effects of various watershed management practices on water resources. It was found that the watershed management practices that could enhance the sustainable management of the watershed are the construction of a reservoir with a storage capacity of 100 million m^3, enforcement of minimum flow requirement in Arror River, the use of contour farming in agricultural lands, agroforestry, conservation of the forest cover, application of more efficient irrigation methods and keeping of an optimum number of livestock. The residents of Arror watershed should integrate both traditional and modern methods of water resource and watershed management practices.

It is therefore recommended that a reservoir whose main purpose will be irrigation, domestic water supply and generation of hydroelectric power should be constructed in the watershed. This will ensure water availability throughout the year and in all parts of the watershed (upstream, mid-stream and downstream). It will also help in reducing soil erosion and floods in the watershed. Secondly, the maintenance of minimum environmental flows in Arror River should be observed. This will lead to minimized water shortages in the watershed and enhanced ecological sustenance of the river ecosystem. Lastly, on soil conservation, the farmers should be encouraged to practice contour farming and terracing especially on steep slopes. This will help check the rate of runoff on the steep slopes hence reducing soil erosion. This in the long run will help in minimizing soil degradation, flooding and landslides during heavy rainfall seasons as well as sedimentation of the water bodies. In addition to this, there will be other benefits such as increased revenue from agriculture, livestock keeping and industry and hence the improvement of the economy of the region. We hope that the findings of this study together with the discussions will inform the stakeholders on the best management practices that will enhance sustainable water resources management in Arror watershed and other areas with similar conditions.

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