

Analysis of Unintended Lake Formation Problem and Its Environmental Effects a Case Study

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Abstract

Waterlogging and unintended lake formation become the main problem in some parts of the world. Starting from 1989, the waterlogging problem was observed in the farmland of the Jarso community of Konso Woreda adjacent to the Segen River in Ethiopia. Therefore, the objectives are determining the extent and causes of unintended lake formation using GIS/RS in addition to a preliminary field survey to mitigate the problem. The analysis of satellite images revealed that over the years invasion of the irrigable land by unwanted water had increased, as, in 1989, the size of the wetland area was about 8 Km²; in 2000 the size of the un-intended lake was only 8.23 km². Alarmingly the size of the lake increased to 19.68 Km² in 2014. Silting up of Weir and changing the flow of River Segen and Human Intervention and changing the natural flow of River Yanda were the main causes of this unwanted prolonged water-logging. The ecological and social environment has been degrading as the people of the waterlogged area have been experiencing some settlement and losing their land. Another problem encountered was flooding from River Barka and invasion of the farmland. Sediment control best management practices (BMPs) i.e, Removal of sediment, providing sandbags and well-scheduled maintenance; Changing the junction point of Yanda and Segen River were suggested for the long-term and short term possible remedial measures. Gabion retaining wall on the bank of the Segen River to the face of Barka River was suggested to protect the farmland from flooding.

Key words : Waterlogging, GIS/RS, Unintended lake Formation, Environmental effect

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1. INTRODUCTION

Agriculture is the backbone of the Ethiopian economy (Teshome 2006). In Ethiopia; agriculture supports about 85% of the population in terms of employment and livelihood (Deressa 2007). The current Ethiopian population is predicted to increase at a rate of 2.5% annually (UNDESA 2015). Ethiopia is also one of the countries which are on the verge of development and the food consumption pattern is expected to increase in the near future (Gebrehiwot and Gebrewahid 2016). The high population growth rate coupled with increased per capita food consumption will highly increase the food demand of the country which cannot be fulfilled simply with the existing production level (Schultz 2001). The development of irrigated agriculture is necessary for fulfilling the rising food requirements of the burgeoning global population (Singh 2015). The Ethiopian government had put irrigated agriculture at the heart of its development strategy (Devereux et al. 2005; Van Den Berg and Ruben 2006).

In the past, the economic activity especially with the respect to crop production was very low due to malaria and conflict in the study area. That is why the area becomes venerable to a chronic type of food insecurity for more than four decades. Currently, the very nature of the area, however, converted to dominant economic activities because of spate irrigation implemented on Yanda and Segen Rivers to sustain different mixed cropping systems. Yanda and Segen Rivers are the two Rivers contributing to the Yanda faro Segen Sewate spate irrigation project. Ten (10) spate irrigation diversion weirs were constructed (7 on Segen and 3 on Yanda). In Yanda Segen Sewate area, there is a lake through which Segen River comes across. Previously, this lake was very small in area coverage but now a day its continual expansion has created immediate hardships for residents, particularly farmers who have lost large parcels of productive lands.

The beneficiary communities are farm families residing in various villages in the mid/highlands of Jarso and Birbirs Peasant Association. Accordingly, the project has relieved the life of communities through constructing different hydraulic schemes for 6000ha of the command area. But due to anthropogenic and natural factors, various challenges have been occurred on these schemes out of which unintended lake created along the Segen River has significantly invaded the farmland of the Kondo farmers.; the main assumed problems for this invading may be due to: (1) Community intervention to the environment both at on-site and off-site may have implied negative impact on environment, (2) River morphology may be affected due to development intervention, (3) Rainfall pattern variation may be also another issue for lake invading, (4)

Sediment accumulation from the Rivers may have influenced the lake. Therefore, these major problems are the reasons for initiating this task and call for professionals to get appropriate factors and remedies on the unintended lake. As it was observed, the area finds difficulties to utilize the maximum potential of the command area as unintended lake created along the Segen River has significantly invaded the farmland of the farmers. Generally, the socio-economic condition of the project area is suitable to undertake any developmental activities. As a result of this, it is very crucial as well as recommendable to control the unintended lake created in the case to ensure sustainable development in the study area. Therefore the objective of this study was to analyze the cause and extent of the unintended lake formation and to recommend remedial measures.

2. Materials and Methods

2.1 Study Area

Yanda-Faro spate irrigation is located in the Eastern part of Jarso kebele of Konso town. It is situated at 5°15' N latitude and 37°30' E longitude .the catchment of Yanda River is the catchment that supplies flood water to Yanda-Faro spate irrigation systems. The catchment(Fig 1) is the sub-watershed of Segen watershed. The catchment can be broadly divided into lower and upper sections. The lower section with an average altitude of 876 m and the upper section with average altitude 1456m constitute an area of nearly 51244.2 ha. The source of floodwaters for the low-lying Yanda-Faro spate irrigation command area is the hilly mountainous area with elevations ranging from 876 to 1974m. There are fragmented farmland holdings on the hill-sides of the upstream terrain and at the foot of the highland. Yanda ephemeral stream is around 30km from Karat, the capital of Konso.

2.2 Climate and Soils

The Konso area receives an erratic and uneven distribution of rainfall during the major and minor rainfall seasons. Mean monthly rainfall of 13.93 mm in February and maximum monthly rainfall of 160 mm in April (Fig 2) and mean daily temperature of about 28°C were observed at Karat station of Konso. The Yanda-Faro plain falls under the Kolla agro-climatic zone, which can be classified as a semi-arid tropical lowland climate. The area is situated in a dry belt with very unreliable rainfall. The distribution of rainfall is extremely uneven in time and space, resulting in serious water shortages, which characterizes the impracticability of rain-fed agriculture.

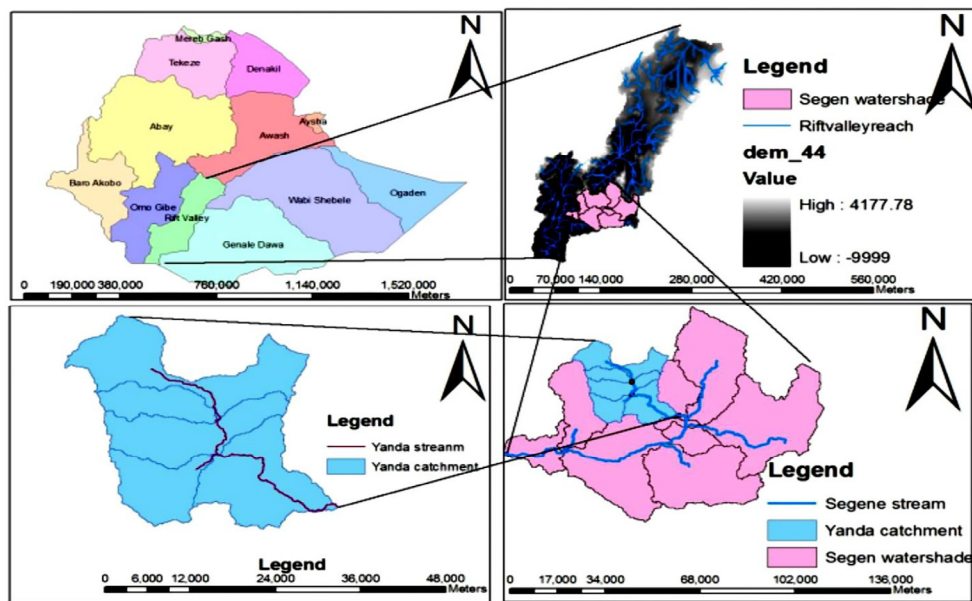


Fig 1. The location of Yanda catchment and the study area.

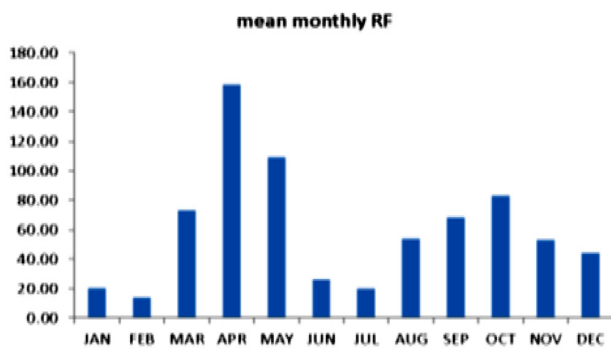


Fig. 2. Average monthly rainfall of Karat station, Konso, (analyzed for 10 years [2000–2009] data)

The Konso highland is basalt massive, which runs east to west across the bowl of the Great Rift Valley. Therefore, the soils of the area are of volcanic origin. In the lower parts near the Yanda River, the soil is very fertile and consists of fine alluvial deposits. The Yanda–Faro spate irrigation command area is characterized by alluvial soil types of rich silty loam with high permeability.

2.3 Data Acquisition (Primary and Secondary Data)

2.3.1 Topographic Surveying, Soil sample, and Infiltration:

Topographic surveying of the Segen River was undertaken to start at a section upstream of the un-intended lake (UTM 37 N 668276.2 Easting, 339191.5 Northing) and extending down to a nearby section of the River to the bridge. The required amount of topographic surveying was taken for River Barka and River Yanda as well.

Soil from two sample points was collected – one from farmland and one from the Riverbank below the bridge. The

soil samples brought to laboratory tests for further investigation. The soil texture of the Yanda–Faro spate irrigation command area was carried out using hydrometry method in the laboratory. To perform the test, each soil sample was mixed thoroughly to form a composite sample for the topsoil and the sub-soil. They were then subject to the standard procedure of the hydrometer method.

Infiltration (soil water intake) is the rate at which water enters into the soil from the surface. It is of great importance to surface irrigation design and management. There are four commonly employed methods and instruments for the measurement of infiltration, namely, double/single ring infiltrometers; ponding; blocked recirculating infiltrometer; and a deduction of infiltration from evaluation of the advance phase and the tail-water (Vlotman et al., 2020). In this study, a double ring infiltrometer was used to measure the infiltration rate in the Yanda Faro spate irrigation command area. The infiltration rate is important for the selection of suitable methods and designs for irrigation systems and management techniques. It provides information for estimating irrigation efficiencies, required farm turnout capacities and deep percolation losses, and as a guide to desirable irrigation practices. It also used for distinguishing land suitability classes. The measurement was conducted until the constant intake rate was obtained. The records were entered on a form prepared for this purpose. Finally, the instantaneous, cumulative rate and time were calculated.

2.3.2 Land use land cover scenarios(Image processing and Image classification)

To recognize the service provided by the natural ecosystems as well as to recognize extent wetland expansion, Satellite images

of different temporal were used and analyzed from the year 1989 to 2014. The following tabulated data is indicating detail of type, source, resolution, and temporal of utilized satellite images.

Table 1. Lists of Satellite Image used in this study

Satellite image	resolution	Date	Source
Landsat 5 TM	30	15, 11,1989	USGS
Landsat 7 ETM+	30	28,11,2000	USGS
Landsat 7 ETM+	30	16,12, 2014	USGS
SPOT-5	20	16,12, 2013	Map Agency

Digital image processing of satellite images (from the year 1989 to 2014) was executed to visualize the overall change pattern of the un-intended lake and athwart dispersal of water over the years using digital image processing software, ERDAS Imaging 9.2. At first, the collected satellite images were transformed into Universal Transverse Mercator (UTM) projection to analyze with ease. After georeferencing with controlling points and projecting the images into the same projection parameters (UTM), images of different years were overlaid to extract the real situation environmental ecosystem service.

A supervised classification through the maximum likelihood algorithm was applied to perform image classification. Accordingly, based on a FAO land use maps, modified version of Anderson land use land cover scheme levels I and II (Anderson, et.al, 2001), NDVI value of landscapes and the team's knowledge of the study area: five major classes of land use land cover were identified (i.e. Vegetation/forest, cropland, woodland, Grassland, and Wetland/waterlogged area). Land use land cover maps derived by remote sensing frequently present various errors as a result of either one or both factors classification techniques or the method of satellite data capturing. Therefore, classification accuracy assessment is an important step in evaluating image classification. Consequently, classification accuracy has been conducted using different ground truth data including high resolution map SPOT image, collected land use information by interview and GPS, Google map, and topographic map. Therefore, Classification of satellite image data was performed integrating field data, topographical maps, medium resolution satellite image (SPOT 20 m), and visual image interpretation.

The main reason behind this image classification is to recognize the extent of the water affected/waterlogged part and other environmental conditions temporally and spatially. Then, the waterlogged area and environmental condition of the project from the year 1998–2014 were identified based on the above

classification mechanism and correlated to the ground truth. All the GIS layers used in this study were derived from the analysis of collected images exporting as coverage files using the aforementioned digital image processing software and then transformed into shapefile (.shp) layers using GIS software, ArcGIS 9.3. Illustration of final maps and lake expanded area calculations were conducted in the ArcGIS 9.3 platform.

3. Results and Discussion

Due to rapid development, land cover is subjected to changes causing many soils to become impervious surfaces. These lead to a decrease in the soil infiltration rate and consequently increase the amount and rate of runoff. Deforestation, urbanization, and other land use land cover activities can significantly alter the seasonal and annual distribution of soil loss and surface runoff. Thus, to understand the land cover and land-use change process and its implication for environmental and ecosystem functioning, it is important to recognize the services provided by the natural ecosystems and to come up with a sustainable land use plan. The onsite infiltration test at the study area shows infiltration capacity of 20 cm/hr (Fig 3)

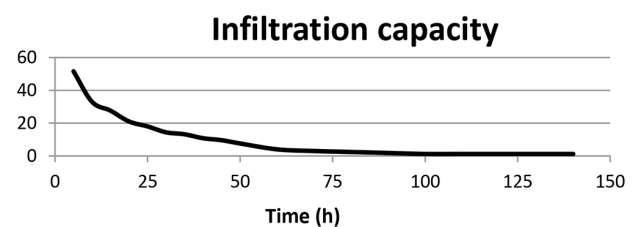


Fig. 3. Infiltration capacity curve at the study area

3.1 Laboratory observation of soil samples

The physical analysis was conducted for the determination of soil water holding capacity, bulk density, porosity, and texture classification. The results obtained indicated that the soil samples taken from fields were found to be predominantly silty clay loam and silt loam .the results of texture analysis are presented in Table 2.

Table 2. Soil textural classification of Yanda–Faro Segen Sewate area

sample	% Sand	% Silt	% Clay	Texture class
sample on downstream field	9.25	51.28	39.47	Silty clay loam
Sample at River bank	59.28	18.20	22.52	Sandy clay loam

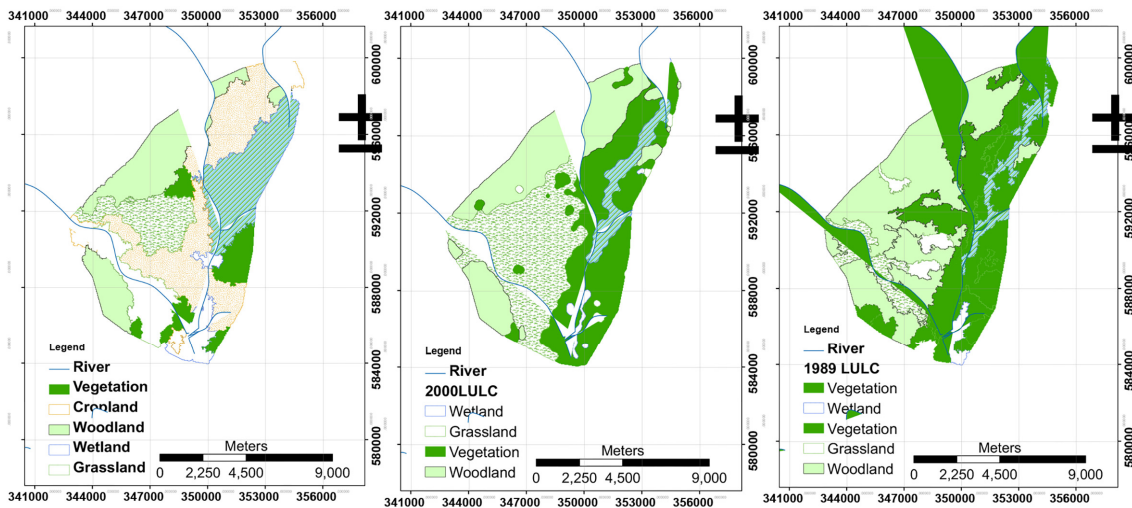


Fig. 4. Waterlogged area over the years from 1989 to 2014; (a) Waterlogged area in 1989; (b) Water–logging extent in 2000; (c) Waterlogged area in 2014;

The Extent of land use land cover of lowland of Konso especially Yanda Fero segan sewate project area from years, 1989 to 2014 has been analyzed(Fig4). Analysis of classified map shows that Vegetation and woodland were the most dominant LULC type in Yanda faro project area before the initiation of the project which means before the year 2000. But from the year 2000 to 2014 Wetland/waterlogged area was highly intensified by affecting other LULC units in the project area. As the main objective of this study was to tackle the problem of waterlogged area expansion, more focus was given to the extent and factor causing this waterlogged area expansion.

Therefore, the extent and percentage change of the waterlogged area of Yand faro project area over the study period has been analyzed. The spatial extent of the waterlogged area of the year 1989, 2000, and 2014 from classified images(Fig 4) show that a major change had occurred in the region. The following table shows the extent of waterlogged conditions from the year 1989 to 2014.

Between the years 1989 and 2000, the extent of the lake was almost with a constant trend(Fig 5). When the classified image of the site is checked, there was an alarmingly increased of the un-intended lake. From the commencement period of the project towards the year 2014, the lake coverage was increased by about 130%.

In 2014, About 11 km² of the Irrigable land is submerged by water and abandoned from irrigation, If this decrepit scenario of Segen River continues, within the next decade, more 22 km²

Table 3. Extent of inundation over the years (1989–2014) at the Segen–Sewate Basin Area derived by analysis of satellite images

Water Logging Extent	Years		
	1989	2000	2014
Water logged area (Km ²)	8.00	8.23	19.68

of the irrigable land would have been abandoned and the damage continues up to downstream reach. It would have been damaged the irrigation infrastructure, i.e; Weir and conveyance systems in the area which is again a big loss for the whole system.

Major land use land cover changes have occurred at the local level for all land types similarly. For instance, a significant increase in cropland at the expense of vegetation and woodland was found to have occurred between 2000 and 2014. Such local–level dynamics are very important in determining the status of land and ecosystem health. Hence, information on land use, land cover, and possibilities for their optimal use is essential for the selection, planning, and implementation of land use schemes to meet the increasing demands for basic human needs and welfare. This information also assists in monitoring the dynamics of land use resulting from the changing demands of the increasing population. Studies of rates, extents, patterns, causes, and implications of land use and land cover dynamics at the local level can help to design appropriate land management practices, strategies, and policies.

The driving forces of this dynamic change of local land use land cover are population growth changes in people’s needs and activities. These change lifestyles and overall levels of production and consumption, which in turn exert pressures on the land. Unless appropriate measures are taken alongside, the consequences of a high population in a situation of limited resources and services are appalling.

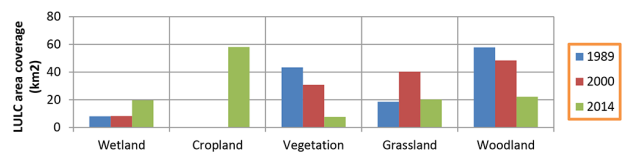


Fig. 5. The extent of land use land covers changes from 1989 to 2014

3.2 Identified Causes of Un-intended Lake Formation

Water area coverage at Lake Yanda Faro Segen Sewate has increased and the surface area has moved and expanded in all directions especially to the west, invading lands that were being used for agriculture. This slow progressive flooding process could be the result of different factors in the basin. This report means to assess those factors in the area of the Yanda faro Segen Sewate basin. To achieve our goals, we performed land use land cover classification for different periods, assessment of the topographic property of the basin, analysis of infiltration capacity of the soil, and investigating the negative impact of anthropogenic/development activities. Naturally in the closed lake, lake expansion is related to climates change in the region (evaporation, wind speed, etc.), possible groundwater intrusion, Land use changes, and precipitation increase. Most of the effect of these factors is obtained by analyzing the water balance of the lake but as this lake is an open lake and expands only during the wet season, the contribution of groundwater and climate change was undermined in this study. The root causes of the un-intended lake were identified through different technical procedures: site visit, satellite imagery, surveying data, etc, and presented as follows.

3.3 Silting Up of Weir and changing flow of River Segen

The weir constructed on the Segen River at the upstream side of the lake has contributed to the expansion of the lake as it is affected by the sediment. Most of the water coming across this weir is flowing to the command area during high flow period and during low flow period due to sediment-filled on the weir, this all shows that there should be well-managed activity on constructed water structures with regarding sediment control. Rivers in spate also lift and deposit huge quantities of sediment and hence sedimentation is as important as runoff water management. The important part of spate irrigation is how to deal with sediment. The sediment over the weir has to be removed successively.

3.3.1 Human Intervention and changing the natural flow of River Yanda

As it was observed during the site visit, the expansion of the lake is towards upstream as well as somewhat to the right side of the lake. Consequently, to find the cause of expansion, surveying has been conducted to assess the topographic features of the land surrounding the lake. From the surveying data simply it can be recognized that as there is elevation variation in between upstream and downstream of the lake.

Surveying data shows that from 1 to 1.5m more elevated at downstream of the lake than upstream when Yanda-Segan River junction and lake points are observed. To identify the reason for this variation field investigation and interviews with the community have been conducted. Accordingly, River Yanda is the most sediment contributing River at the immediate interaction with the Segen River on the downstream of the lake. Starting from this point towards the down course of the River, the flow velocity of the River becomes less due to the minimum slope and result in sediment deposition.

Hence, the sediment deposited at this junction and in the River course creates elevated areas than upstream land. Normally, the previous junction point of the two rivers was not at the current position. As the community explained and the site visit prevails, the junction point of the two Rivers was at some distance down to the current one and due to highway construction on the River, Yanda River course has been changed to the current point. Additionally, another River Berka with high sediment load is joining the River at some distance down to the junction of Yanda below the bridge, and the Segen River being converted from its previous course. Therefore, due to the development activity and natural reaction of the area, the elevation variation has been created across the vicinity of the lake. Due to this fact that more sediment from Yanda River comes and deposited on the Segen River, at the junction point which causes the head at junction point to increase as compared to the level of the lake, as a result, water is flowing back to the lake formed. This causes the level and extent of the lake to increase.

Therefore, to make the system sustainable and safe the course of River Yanda would be changed to its natural flow in which the junction point between the two Rivers would have to be shifted to down near to the bridge(Fig 9). The sediment at the junction point would have to be removed.

3.3.2. Rainfall distribution and its consequences

There is no documented reports and presentation on the pre-project history of the Segen Sewate lake formation and expansions. In an attempt to fill this gap, lake formation and expansion information were determined based on a long time air-born satellite image going back to 1989. The result indicates that and confirmed by informal local knowledge as there is a clear unintended lake formation mostly starting from the year 2000 towards during the wet season.

To find out the reason and factor behind this expansion, different researchers and concerned bodies have assessed for a long time, however, there is no identified specific factor for lake formation and expansion but only assumptions. Differently, Segen Sewate Lake which is open basin lake has been expanded

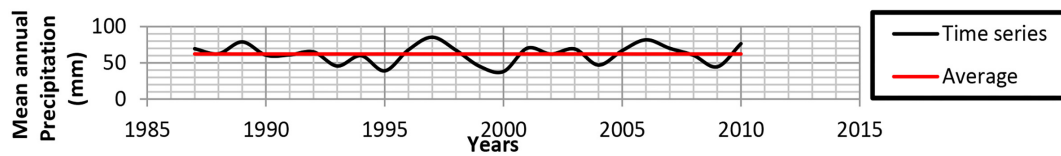


Fig. 6. Precipitation time series of Konso town.

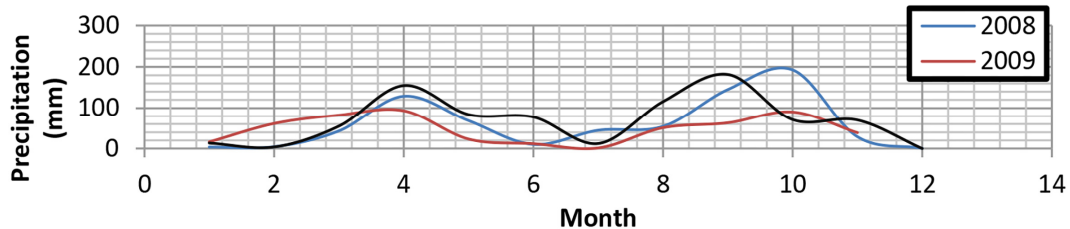


Fig. 7. Monthly variation of precipitation.

and affected large productive farmlands recently. As a result, the aim of this study was mainly to investigate and control lake formation and expansion factors. Hence, the first assumption is that the somewhat anomalous pattern of lake expansion is due to rainfall pattern variations. Accordingly, rainfall data obtained from Meteorological agency starting from 1987 to 2010 has been analyzed to examine the magnitude variation of rainfall whether it is the factor for lake expansion. The magnitude of precipitation varies with time and space. Differences in the magnitude of rainfall in various seasons of the year are obvious and need no elaboration. It is this variation that is responsible for many hydrological problems, such as floods and droughts. The study of precipitation forms a major portion of the subject of hydrometeorology.

According to this study, the precipitation regime is characterized by a medium degree of interannual variability. Over a two decadal to the year time scale, a cluster of consecutive years with oscillation below and above-average precipitation occur in sequence. Fig 6 below indicates that between 1987 through 1996 the region experienced a run of years with mostly below-average precipitation but from 1996 onward with typically above-average precipitation.

Unlike other lakes, Segen Sewate Lake is a dynamic lake that varies significantly in character depending upon the regional moisture conditions. During significant wet spells, the plain landscape will experience an explosion in lake quantity and size, and in contrast, during dry spells, it shrinks both in size and area coverage. As it is an open lake, which means inflow is equal to outflow; it may not create an exaggerated volume change of the lake. As a result, it is difficult to wrap up that the rainfall variation from the nearby basin is the cause of the expansion of the lake. Hence, a further and detailed investigation that considers all the parameters affecting lake expansion was conducted to justify the cause for the expansion.

Fig 7 shows the monthly variations of precipitations in the study area

The water level changes of open basin lakes are a function of precipitation distribution variation, changes of land use in their watersheds, and morphological features in the vicinity of the lake. Moreover, as the catchment is ungauged catchment precipitation is used to have a rainfall-runoff relationship. Estimating extreme flood discharges for specified return periods are needed to design different structures. Several methods can be used to analyze this discharge. The SCS and unit hydrograph combination based on a daily maximum rainfall, a time of concentration derived from catchment parameters and catchment characteristics are used to derive it. The following graph (Fig 8) shows the extreme value of runoff coming to the outlet or the bridge site once in fifty years.

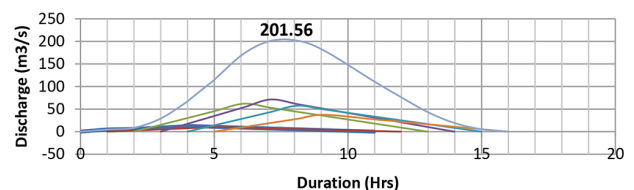


Fig. 8. Peak flood of the catchment for the return period of 50 years at an outlet.

4. Conclusions

In this study, primary and secondary data were used for determining the extent and causes of unintended lake formation in the Segen Sewate area. GIS/RS techniques in addition to a preliminary field survey were one of the approaches used to determine the extent of lake formation. The satellite images of the study area from the base year 1989 to the year 2014 were analyzed considering the hydro-meteorological parameters. With the field survey, soil laboratory test and

infiltration test, and the outcomes of the analyzed secondary data (satellite images and ground truths) root causes for the enlarging unintended lake at the study area were identified.

Satellite image analysis revealed that over the years invasion of the irrigable land by unwanted water had increased, as, in 1989, the size of the wetland area was about 8 Km²; in 2000 the size of the un-intended lake was only 8.23 km². In 2014, the lake invasion increased to 19.68 Km². Silting up of Weir, changing the flow of River Segen, Human Intervention, and changing the natural flow of River Yanda were the main causes of the unwanted prolonged water-logging. The unintended lake formation results in degrading displacement of the local community and losing their land. Occasional flooding from River Barka and invasion of the farmland was also among the problem. Sediment control best management practices (BMPs) i.e, Removal of sediment, providing sandbags and well-scheduled maintenance; Changing the junction point of Yanda and Segen River were suggested for the long-term and short term possible remedial measures. Gabion retaining wall on the bank of the Segen River to the face of Barka River was recommended to protect the farmland from flooding.

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