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GIS and REMOTE Sensing Based Water Level Change Detection of Lake Hayq, North Central Ethiopia

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Abstract

This study investigates the response of Lake Hayq water level change over the period of 1972 to 2012. The purpose of this study was to show the water level change of Lake Hayq and the management practices for this change. The water level change of Lake Hayq was assessed by examining the water balance of the lake. Precipitation, runoff from the watershed area, evaporation and surface outflow from the lake are the major components of water balance of Lake Hayq. Penman's combined energy balance and mass transfer approach formula was used to calculate annual evaporation rate of the lake. The resultant of water balance of the lake Hayq show that annually 0.9×10^6 m^3 of water misplaced from the lake. The width of the isthmus of Lake Hayq has increased from 33 meter, to 108 meter and 163 meter in the years 1972, 1986 and 2012 respectively. As such, any fluctuations in the area and the level of the lake can be imposed by both natural and anthropogenic forces. Some of the natural factors are drought, topography of the watershed, erodibility of the soil, and variability of the rainfall. Some of anthropogenic factors are over pumping of the lake water for irrigation, inappropriate use of wetland, LULC change and deforestation. In order to keep the natural balance of the area wetland management in the buffering zone, studies based use of lake water for irrigation, afforestation, and soil conservation program are must be needed.

Keywords: Water Balance, lake level, Lake Hayq, Ethiopia

1. Introduction

Lakes are vital resources, providing water, food, a diverse biota and recreational facilities. Majority of the lakes in Ethiopia are found in the Rift valley basin. The total surface area of these natural and artificial lakes in Ethiopia is about 7,500 km^2. However, Ethiopian lakes have suffered changes in their hydrological balance (evaporation rates inputs from surface and ground water sources); reduction in the quality of water resource including deterioration of geochemical balance (including salinity, oxygen depletion); disruption of ecosystem (eutrophiction, decrease in biological diversity); and the exposures of lake beds to the atmosphere resulting in toxic dust emissions (Julie, 2008).

Lake Hayq is a highly valuable resource area. It is a focal point for tourism, it attracts who appreciate their natural beauty, or who come to swim, or explore. It has long been important to lake area inhabitants as a food resource and for their religious and cultural associations and it appreciates peoples to invest their capital at its surrounding area. However, using lake in these ways has altered lakeshores through artificially manipulating lake levels. The lake edge is the interface between water and land. It is often a region of dynamic physical processes, and high biodiversity and productivity, and it is also serving as a crucial habitat for terrestrial and aquatic plants and many invertebrates, fish and birds during all or part of their life cycles (Tadesse, 2010).

Lake Hayq provides a habitat to different fish species, water birds and aquatic organisms. It also plays an economical role via tourism and fishery, and most importantly it provides drinking water to the local inhabitants (Tadesse et al., 2011). But the water level fluctuations are known to contribute to the loss of great diversity of ecology and socio economic development. These environmental challenges might likely damage the fish fauna, phytoplankton, zooplankton and other species as well as the lake ecosystem (Workiye, 2009**).** Baxter and Golobitsh (1970) observed that the water level of lake Hayq was appreciably lower at the time of their visit in January 1969 than in May 1938. The island near the west shore, on which a monastery is located, was attached to the shore by a low isthmus, covered with vegetation. It was also reflected in group discussion with local elders that the amount of water level in the lake is decreasing gradually. Moreover, the Ankwarka River is the principal inflow to Lake Hayq an apparent palaeochannel now permanently dries (Tadesse et al., 2011**)**.

By considering the above arguments, this study was focused on the extent and trend of change occurred in Lake Hayq. It was intended to suggest solution to overcome problems associated with water level change and ecological disturbance of Lake Hayq. Specifically this study is designed to examine the water balance, investigate the water level change, and identify the causes for water level change of Lake Hayq.

Description of the Study Area

Lake Hayq is located in the north central highlands of Ethiopia. It is a typical example of highland Lake of Ethiopia with volcanic origins. Geographically it lies between $11^0 3'$ N to $11^0 18'$ N latitude and $39^0 41'$ E to $39^0 68'$

E longitude with an average elevation of 1911 meter above sea level. The Lake has a closed drainage system and the total watershed area is about 77 km^2 of which 22.8 km^2 is occupied by Lake Hayq. According to Molla et al. (2007), the average depth of Lake Hayq is 37 m, and the maximum depth is 81 m. The only stream that entering the lake is the Ancherka River, which flows into its southeast corner, but now permanently dry due to upper irrigation scheme and it is known, there is no drainage out of it. According to Tadesse et al., 2011, Lake Hayq is classified as a small highland lake with fresh water. It has never been saline; the predominant cations and anions are magnesium and carbonate/ bicarbonate, respectively (Figure 1).

Figure 1: Location map of Lake Hayq in respect to Ethiopia and Amhara regional State

2. MATERIALS AND METHODS

The study used rainfall, temperature, sunshine and wind speed data of the study area obtained from the Ethiopian Meteorological Agency at Kombolcha Branch and for the years between 1975-2012 water level data of Lake Hayq were collected from Ministry of Ethiopian Water Resource. The responses obtained from six Focus Group Discussants in a series of sessions concerning soil degradation, source of energy, expansion of agricultural and grazing land, and Lake Hayq water level change were the main source of information for this study.

A functional daily water balance model, incorporating measurements of inflow, precipitation on the lake Surface, evaporation, and outflow was developed. The equation of water balance of the lake in general form is given by (mm): R (inflow) + P (precipitation) – Ro (outflow) – E (evaporation) = ∆H (water level change). Evaporation is one of the most important components of the water balance. The evaporation from open water calculated via equation of Penman. The Penman method is based on the parameters including temperature, wind speed, radiation balance, and humidity (Elizabeth, 2005). Historical time series data on, rainfall, temperature, sunshine, wind speed and water level data have been used in the analysis water level change of Lake Hayq. The recorded Continuous water levels data (1975 to 2012) and bathymetric maps of Lake Hayq were used to analyze the change of water level and depth of the lake, and finally the results were described through tables and charts. In addition to this, by using the capabilities of ArcGIS 10 spatial analysis and Arc hydro tool, the previous lake Hayq surface area coverage was extracted.

The most basic form of hydrological model of Lake Hayq is simple water balance between input and output, such that:

$$AH = P_W + S_i - (E_W + S_O)$$

Where,

AH = is a change in lake level from the preceding year
Pw = input is precipitation Over the lake
Si = surface in flow from the watershed area
Ew = evaporation over the lake
So = out flow from the lake for irrigation and other domestic usage

Therefore, after the estimation of direct rainfall over the lake by using ArcGIS 10 (IDW) interpolation technique, and calculation of long term mean annual water balance values of Lake Hayq by Penman's combined energy balance and mass transfer approach formula the water balance of Lake Hayq was estimated.

The results the responses obtained from a series of group discussion were analyzed using terms such as the majority, most, and a few to generalize findings in relation to each other and with the remotely sensed products.

3. RESULT AND DISCUSSION

1 Water Balance of Lake Hayq

Our initial water balance estimate utilized the following equation, and calculating the input and output terms as indicated in the following sections.

i Precipitation over the Lake and the Watershed

In general, precipitation is the major input for water balance models. The accuracy of measurement and computation of precipitation from a network of stations determines to a considerable extent on the reliability of water balance computations. In regarded to these, by using ArcGIS interpolation capabilities, the direct precipitation on the lake is interpolated by IDW(Inverse Distance Weighting) techniques from one rainfalls station in the watershed area and two rainfalls stations very near to the watershed area (Figure 2).

Figure 2: Precipitation map of Lake Hayq watershed area.

ii Surface Runoff

Before three decades there was a permanent stream that feed the lake water. According to Baxter and Golobitsh (1970), The only stream of any size entering the lake is the Ancherka river, which flows into its southeast corner. The lake has no visible outlet. However, at present these lakes are terminal and there is no known surface outlet due to the irrigation scheme upstream (Tadesse, 2010).

Surface runoff refers to the precipitation that falls on a land area and eventually flows down slopes together in streams, lakes and other water bodies. When rainstorms are extreme, precipitation may completely saturate the surface soil layers and water will flow over the land surface. It is important for water balance studies to know different runoff components and their regimes because the amount of surface runoff can vary significantly depending on topographic features and the balance between precipitation and evaporation in the drainage basin.

According to Molla et al. (2007), the number of runoff components to be analyzed depends on the characteristics of the basin and the objective of the separation, including the time base to be considered. The surface water inflow is estimated after quantifying the runoff coefficient. This is estimated based on field observations of land use, topography and geology and after aerially weighing land use, soil type and slope classes using a Geographic Information System (GIS). The weighted mean runoff coefficient for the watershed is 0.3. After this, the total volume of surface runoff of Lake Hayq watershed was estimated as below. According to Garg (1987), the Runoff for the watershed is given by;-

$$Q = K*P*A*m^3$$

Where;- Q =is the runoff from the upper watershed

A =is the area of the watershed (54.2km^2);

P =is the mean annual precipitation (1235 mm); and,

K =is runoff coefficient which is 0.3

Accordingly, the mean annual runoff generated from the watershed is estimated to be 20.0 million cubic meters.

Evaporation over the Lake

The most common methods of estimating evaporation over a lake surface are Energy balance and Penman combined energy-budget mass-transfer approach (Dawin, 2010). Both rely upon calculations of the radiation balance and heat transfer terms over the lake, which requires a multitude of input data including sunshine and wind speed over the lake, surface water temperature, and surface air temperature.

The researcher is estimated the evaporation rate of Lake Hayq by using Penman's combined energy balance and mass transfer approach. The penman equation reads;-

$$P_E = \frac{AH_n + Ea}{A + \gamma}$$

Where;-

P_E = potential evaporation that occur from free water evaporation [mm day^{-1}]

A = slope of saturation vapor pressure *vs* temperature curve at the mean air temperature [mm of Hg]

H_n = net radiation of evaporable water [mm day^{-1}]

E_a = parameter including wind velocity and saturation deficit [mm day^{-1}]

γ = psychometric constant [mm of Hg]

The net radiation of evaporable water of Lake Hayq can be calculated in the following formula,

$$H_n = H_a(1-r)\times\left[a + b\frac{n}{N}\right] - \sigma Ta^4\left(0.56 - 0.092\sqrt{e_a}\right)\times\left[0.10 + 0.90\frac{n}{N}\right]$$

Where;

H_a = incident solar radiation outside the atmosphere on a horizontal surface [mm day^{-1}]

a =A constant depending upon the latitude Ø [0.29 cos Ø]

b = A constant with an average value of 0.52 []

n = Actual duration of bright sunshine [hour day^{-1}]

N =Maximum possible hours of bright sunshine based on latitude [hour day^{-1}]

σ =Stefaned - Boltzman constant= 2.01×10^{-9} []

r =Reflection coefficient albedo water surface []

Ta =Mean air temperature [ºk]

e_a =Actual mean vapor pressure [mm of Hg]

$$E_a = 0.35 \times \left[1 + \frac{u_2}{160}\right] \times (e_w - e_a)$$

In which; $u_2 =$ Mean wind speed at m above ground [km day^{-1}]

$e_w =$ Saturation vapor pressure at mean air temperature [mm of Hg]

$e_a =$ Actual vapor pressure [mm of Hg]

$$H_n = 14.15 \times (1 - 0.05) \times \left[0.285 + 0.52\frac{7.8}{12.2}\right] - \left(2.01 \times 10^{-9} \times 291.4^4\right) \times \left(0.56 - 0.092\sqrt{11.91}\right) \times \left[0.10 + 0.90\frac{7.8}{12.2}\right]$$

$= 8.03 - 2.37 = 5.93$ mm day^{-1}

$$E_a = 0.35 \times \left[1 + \frac{128.7}{160}\right] \times (19.84 - 11.91) = 5.00 \text{ mm day}^{-1}$$

$$P_E = \frac{(1.2 \times 5.93) + (5.00 \times 0.49)}{(1.20 + 0.49)} = 5.6 \text{ mm day}^{-1}$$

iii Surface out Flow

Abstraction of lake water by human activities are affected the equilibrium of the water balance and the fluctuation of the water level. According to Molla et al. (2007), there is pumping of the lake water without the basic knowledge of the hydrology of the watershed. The major abstraction of Lake Hayq water resources is for the purpose irrigation and other domestic water use. The annual abstraction for domestic water supply of framers and their livestock, Lodges, St' Estiphanos Abune Eyesus Moa monastery, which fetched by plastic bags and pumped by pedal pump from the lake, was calculated 79,200 m^3. According to TWARDO and WWARDO (2012), there are 46 generators (with the capacity of 1000 litter minute^{-1}) and 2 huge (5,500 litter minute^{-1} water pumping capacity) generators around the Lake Hayq. Based on field survey, the abstraction of lake water for small scale irrigation (Figure 3) by the local farmers around the lake in the lower irrigation scheme and St' Estiphanos monastery at the rate of (8hr ^{day} ×20day ^{month} × 5 months ^{year}× m^3) was estimated 2,208,000 m^3 and the abstraction of lake water for medium scale irrigation at Tiggo and Estena pump at the rate (6hr ^{day} ×15day ^{month} × 4 months ^{year}× 5.5m^3) was estimated 237,600 m^3. The total consumption or abstraction amount of water to be calculated 2,524,800 m^3.

Figure 1: Activities of small scale irrigation by local farmers, 2013.

2. Resultant Water Balance of Lake Hayq

The long term mean annual values of the principal water balance parameters for Lake Hayq are depicted in (Table 1). Rainfall over the lake is 22.8 ×10^6 m^3, surface runoff is 20 ×10^6 m^3, evaporation is 46.6 ×10^6 m^3, and surface outflow is 2.5 ×10^6 m^3. Based on these estimated values the water balance of the lake showed annual deficit of 0.9×10^6 m^3, this indicated that due to over abstraction of water, the lake storage constantly reduced.

Table 1: Long term water balance of Lake Hayq in (million cubic meter) (1980-2011)

The current resultant water balance of Lake Hayq is supported by FGD discussions. All participants assured that drought and rainfall variability were experienced in the previous decades; as the result the Ancherka River intensively used by the population lived in upper watershed area. So, after two decades the river was completely dried up and now no inlet river. This activity of the population largely influenced the amount of inflow of the lake. In addition to this, a great deal of water pumped from the lake for irrigation purpose, and these adversely affected the lake level and ecology. Therefore, drought, rainfall variability, as well as socioeconomic conditions like over pumping of the lake water revealed for the water level decrement of Lake Hayq.

3. Water Level Analysis of Lake Hayq

Continuous water levels have been recorded by the Ministry of Water and Resources (MoWR) services since 1975 to 2012 at station on the shore of Lake Hayq, which is located at the south western edge of the lake. This study carried out depth analysis and water level change of Lake

Hayq from the data gathered by MoWR and different researcher findings. Lake Hayq water levels have fluctuated over thousands of years. High water levels were a problem since 1970s. The examined water level data of (1975 to 2012) showed that the water level change of Lake Hayq have been seen in both long-term and seasonal patterns over time.

i. Depth Analysis

The altitude data of the watershed area was collected by ground survey with Garmin GPS-72 at 3 meter accuracy. The altitude at the surface of the Lake Hayq is recorded 1911 masl. The lowest altitude at the watershed line adjoin place of the neighboring watershed area, which is found approximately 570 meter east of the lake is recorded 1934 masl. When the lake level reaches maximum the lake flows east ward to the river bank.

According to Alvarez (1540), at the rainy season the level of Lake Hayq had reached maximum and flow to eastern direction (Figure 4 outlet).

Based on this evidence, the previous lake shape, area and contour model is derived from DEM of the watershed within ArcGIS 10 software (Figure 4). From the model, the profile of the lake had truncated shape but now it has the smooth curve. The area covered with water in 16 century has found to be greater than water area covered currently by almost 5.8 km^2 or 580 hectares. In addition to this, the altitude at the surface of the lake lowered from 1934 meter to 1911 meter, as the previous position (Table 2).

Figure 2: Previous Lake Hayq shape, area and topography model (source; Alvarez, 1540).

Figure 3: Bathymetric map of Lake Hayq (from Morandini, 1941).

The bathymetric maps of the lake over time provide information on the analysis of depth and storage changes of the lake. According to Morandini (1941), cited in Baxter and Golobitsh (1970), the first limnological studies and bathymetry map of Lake Hayq were carried out by Italian limnologists during the 1930s. Some of their morphometric data found in the bathymetric map are presented in (Figure 5).

Based on the first bathymetric map of the lake Hayq, some morphometeric data are presented in (Table 2). The maximum depth of the lake was 88 meters. The perimeter of the lake had 21.7 km length and it covered 23.4 km^2.

Table 2: Morphometry data of Lake Hayq in 1938 (from Morandini, 1941)

Figure 4: Bathymetric map of Lake Hayq (from MoWR, 2000).

According to the new survey result of MoWR (2000), the maximum depth of the lake at maximum lake level (staff gauge 2m) was 84m. Based on the bathymetric map of (Morandini, 1941), and survey of (MoWR, 2000), the depth of Lake Hayq was fall down by 4.2 meters (88.2m-84m).

In 2007, Molla et al. measured the maximum depth of Lake Hayq 81 m. This showed that there is a continuous depth reduction and the depth of Lake Hayq has gone from 88.2m to 81m in 80 years; land use land cover change of the watershed and high rate of sedimentation are the reasons for the decrement of depth of the lake. The previous depth trend of Lake Hayq by different scholars is depicted in (Table 3).

Table 3: Historical survey of depth analysis at Lake Hayq.

ii. Gauges and Benchmark of Lake Hayq

The Lake Hayq has been experiencing a low level water period over the past decades. In 1975, Minster of Water Resources of Ethiopia rooted the benchmark and water level gauge reader of the lake at the southwestern shore of Lake Hayq.

After MoWR stationed the first water level gauge in 1975, different gauges were planted at different area on the basis of high fluctuation lake water. The difference between benchmark and current staff gauge location has been measured. It has been found that the current gauge location is 6 meter lower than the benchmark (Figure 7).

Figure 8-A, depicted the earliest gauge of the lake but at this moment the data collector is not taking reading from this gauge because the level of the lake reduced in a timely manner from the previous position and became dry land at this time. On figure 18-B and C shows the current gauges of the lake. From these gauges the gauge reader collects water level readings at different time, the first one used only in summer when the water level rises and the second one used in both summer and winter season. Both gauges give different readings.

Figure 5: The distance between BM and the current Gauge, 2013.

Figure 6: Different gauges on Lake Hayq at different time, 2013.

iii. Lake Level Volume/ Surface Area Relationship

The bathymetric map and the calculated corresponding of elevation with lake level area volume capacity curve are accessed from MoWR. This is useful to understand the lake level fluctuation of Lake Hayq. However, it is more feasible to determine relative level fluctuations in computing changes in water storage of a lake for the definite period of time. Surface area is the area of a lake relative to a specific water level. Storage of a lake is volume of water accumulated in the basin at a specific water level. Lake surface area and their storage capacity at various water levels were determined from surveys of (MoWR, 2000). Based on these surveys, the storage capacity of the Lake Hayq was 1034Mm^3, the depicting surface area (area curve) and the volume of stored water (storage curve) against the water level of Lake Hayq are plotted in (Figure 9 & 10).

According to Molla et al. (2007), the estimated average volume of Lake Hayq was 988.7 Mm^3. Based on these data the storage capacity of the lake has dropped by 45.3 Mm^3. These data vividly showed that within the seven year history of Lake Hayq much amount of water was displaced from the lake due to sedimentation problem and over pumping of the lake water.

Figure 7: Lake Hayq Elevation area curve (Source; MoWR, 2000).

Figure 8: Lake Hayq elevation capacity curve (Source; MoWR, 2000).

iv. Trends of Lake Hayq Water Level Change.

The difference between the amount of water coming into a lake and the amount going out is the determining factor in whether the water level will rise, fall or remain stable. Historic lake levels in the Lake Hayq show marked fluctuations between an existed of island near the west shore of the lake and after the island changed to peninsula (Baxter and Golobitsh, 1970).

Since 1975, MoWR has anchored several gauges on the basis of high fluctuation lake water. The water level readings (1975-2012) collected by MoWR found from different gauges. It is obvious that readings from different gauges cannot be indicating the water level of the lake because the location of recent gauges anchored inside the surface of the lake when compared to the previous one (Figure 8). The inconsistency of gauge places was the major problem for computing time serious water level readings of Lake Hayq (field survey and personal communication).

The actual situation reveled the reduction of water level as shown in Figure 8(A, B, C). The MoWR had given conclusion based on the water level data from different gauges readings. According to gauge reader information and field survey, it has been tried to determine the periods of each gauges had been used for measurement of water level. The first gauge was used from 1975 to 1983, the second gauge used from 1986-1991, the third gauge was used from 1997-2003 and the fourth gauges used from 2007-2012. For partitioning the general trend water level readings of lake Hayq in correspondence of different staff gauge periods (Figure 11); this study gave consideration data gathered from filed survey and the years that were not taken gauge readings (1984-1985), (1991-1997) and (2004-2005). In addition to this, in 2007, Molla et al. stated that the lake level gauging position has been shifted on the basis of fluctuation of the level.

The water level reading from 1975 to 2012 shows constant decrement of water level, it has been reduced from 88 meter to 81 meter and all water level recorded value indicated that below the benchmark of the lake level.

According to the annual water level (2012/13) recorded data by the author, the annually water level showed a seasonal water level decrement of Lake Hayq. The lowest water levels recorded from January (0.56m) to May (0.33m), and highest is recorded in the rainy season of August (1.93m) (Figure 22). This result showed that there is 1.6 meter annual water level variation. Precipitation, surface runoff, at rainy season; evaporation and extraction of lake water for irrigation purpose at dry season are the major input and output factors for water level change of Lake Hayq.

Figure 9: Water level change trend of Lake Hayq (Source; MoWR, 2012).

Figure 10 : water level change of Lake Hayq (source; Author, 2012/13).

The serious problem was seen in water level change of Lake Hayq in the previous six and seven decades. But, some studies that carried out on the Lake Hayq (MoWR, 2000; Molla et al., 2007), forwarded starting from the late of 1990s the level is constantly raising and the farmer living around the lake lost their farmland due to the increment of water surface area by artificial aqueduct of Ancherka River. But, according to Tadesse (2010), the discharge of water through Ancherka River was disconnected before 20 years ago due to irrigation scheme of upper stream. It is clear that the major inputs for water level change of lake Hayq is rainfall and surface runoff; but from total annual rainfall data there was no more variation between the total annual rainfall received from 1990-2000 and the previous decades. Therefore, it is difficult to describe the level of Lake Hayq based on the recorded water level data.

Based on data gathered from different literature, resultant of Lake Hayq water balance, findings of LULC change of the watershed area, and field survey; this study assured that especially from the recent decades the level of Lake Hayq is decreasing alarmingly and the ecosystem of the lake is disturbed. In addition to this, this study was supported by FGD and key informants. From the FGD, it has been learnt that before seven decades ago Hayq monastery was surrounded by water bodies and was referred as an island. During that time, the people enter to the monastery through boat and swimming but now a day there is a big isthmus that serves as a road to enter the monastery and other land use practices. Lake Hayq area coverage evacuated from time to time; within the previous decades, 104 hectares water bodies were changed to dry land (LULC; Section 4.2.2; Table 8). Most of the FGD participants described that due to this change, the farmers that have farmland around the lake were benefited from the increment of their agricultural land area coverage. In addition to this, the key informant Aba Tesfa-Sellase Wolde-Hanna (monk at St' Estiphanos monastery) 34 meters of the lake became dry land for the past decade when it measured from the location where the key informant marked as the level of the lake before 15 years ago.

3. Causes for Water Level Change of Lake Hayq.

The study described the main biophysical factors of high water level change problem of Lake Hayq especially since 1970 in respect to result of water balance and LULC change analysis of Lake Hayq. The interrelated anthropogenic factors that have a great impact on the water level change of the Lake Hayq identified on the basis of focus group discussions, unstructured interviews and related literature. The discussions helped to understand the human induced factors of Lake Hayq water level change emanated from high population pressure of the watershed.

1. Population and Agricultural Land Expansion

The rapidly growing population, on the watershed took the first hand for LULC change of the area. All of the FGD participants indicated that today like other part of the region for searching of additional farmland and grazing land, agricultural activities expanded up to the periphery area of lake shore and sloppy grounds these owing to increase soil erosion of the watershed area and sediment deposition to lake bottom.

The major socioeconomic factors that revealed the water level fluctuations of Lake Hayq, are the significant over pumping surface water of Lake Hayq to irrigated fields without proper irrigation scheduling and a detailed scientific study and the establishment of irrigation schemes at the upper part of the watershed area this might be blocked the contribution of the neighboring basins. According to TWARDO (2012), there are 60 hectare irrigated field in the upper watershed area with 350 household beneficiaries along the Ancherka River and 146 hectare irrigated field in the lower watershed area with 780 household beneficiaries along Lake Hayq water pump generator project. In addition to these, agricultural land expansions on the periphery area of the lake in the previous decades were the major factors for water level change of Lake Hayq.

To analyze the agricultural practices around the lake shore, the author extracted farmland activities at 30, 50, and 100 meter buffer area of the lake from the result of LULC changes. According to the results obtained from LULC change of farmland on the buffering zone of Lake Hayq, the distribution of the farmland in 1972 was very small. Areal values of farmland for the period of 1972, 1986 and 2010 satellite image classification at 50 meter buffering zone were calculated as (4 %), (38 %) and (66 %) respectively (Table 4), this indicating that such areas were converted to farmland with very fast and continuous trend. These given data expressly stated that the increase of farmland around the periphery of lake areas accelerated by high population pressure.

Table 4: Calculated Farmland practices on the buffer area of Lake Hayq (source; LULC)

It is obvious; these activities disturbed the lake ecosystem. Due to these problem, the Tehuledere Woreda Environmental Protection and Land Use Administration Office (TWEPLUAO) experts (in 2011), informed the level change of the lake in relation with human activities and drew an action plan to protect the ecological disturbance of Lake Hayq. The Federal Government Environmental Protection Authority accepted the plan and gave financial assistance to establishing buffering zone around the lake by planting buffering stone. But, according to FGD participants and ground survey, the buffering stones were planted very near to the lake (in some area approximately less than 5 meter) and the farmers are still expanding their farmland over the perimeter of the lake in buffering area.

This paper assured that, the previous delineation of Lake Hayq buffer area by TWEPLUAO was carried out without the basis of scientific studies result and not covered all around the lake area. This paper extracted the buffer area of the lake in 30, 50, and 100 meter in respect to the LULC analysis result of 2010 satellite image (Figure 13). Human practices around the buffering zone of the lake are very important for the management of the wetland ecosystem by reducing the rate of sedimentation. Therefore, as like the 1972 land covers in buffering zone within 30 meters do not has direct contact of farming and grazing activities.

Figure 13: Farmland Practices on the buffer area of Lake Hayq at 30, 50 &100 meter.

Moreover, the members of FGD discussed that the farmers are used inorganic fertilizer to improved agricultural production. But after a long period of application of inorganic fertilizer, the quality of Lake Hayq was deteriorated through eutrofication process. Aba Tesfa-Sellase Wolde Hanna (monks at St' Estiphanos monastery) said that before 15 years ago the water was very clear and transparent to see things up to 9 meters depth by necked eyes. But now a day's, the clarity and transparency of water decreased and it is not possible to see things up to 3 meters deep.

2. Population and Deforestation

According to CSA (2010), the population of the watershed is increasing alarmingly (Figure 14). All of FGD participants described that there is the shortage of construction material and fire wood in the study area, though all indigenous and other trees from the previous forested and shrub land areas were cut down by people without any conservation measures, this is vividly showed that the rate of deforestation in the watershed area was very high.
Figure 11: The population growth trend of Lake Hayq watershed area.

Due to absence of vegetation cover in the watershed area, heavy rainfall during summer season, long history of cultivation and land degradation; the watershed is exposed for sever soil erosion. Based on the result of FGD recently, the decrement of fertility of plots and the water hold capacity of the Lake Hayq are resulted from the presence of high erosion in the watershed area.

The soil types of the watershed in the sloping area are prone to high erosion and 28% of the watershed found above 12% slope gradient and this implies that the region is more exposed for erosion. Soil erosion is not only the problem of low productivity of the watershed but also its shares the major problems for the water level change of the lake. The eroded soil is transported from the surrounded steep slope of the watershed to all sides of the lake and the eroded material deposited at the bottom of the lake. Especially high sediment deposition was accumulated along the joining area of lake shore and culverts that constructed at the road line from Hayq town to 015 kebele.

In addition to these factors from FGD this paper assured that the shortage of grazing land and the increment of cattle population of the watershed on the study area were enforced the population to graze the wetland area by their livestock. This activity of the community vividly disturbed the ecology of the lake because wetlands are very useful for the home of aquatic animals like fish, birds and the wetland serves as a fence by protecting direct sediments linkage to the lake.

This paper finding is supported by the previous studies that carried out in Lake Alemaya. In 2005, Muleta et al. reported that in the Lake Alemaya watershed soil erosion was caused by deforested lands, the poor land covers, the shallow soil depth, high rainfall intensity, steep topography, poor vegetation cover coupled with cultivation of steep lands and inadequate conservation practices. Owing to these factors in the watershed there was high rate of erosion and the strong capacity of Lake Alemaya was affected by the sediment yield from the watershed.

From field survey, like other area the woreda agriculture office, in the study area the soil management and soil conservation measures like traditional terracing, traditional ditches, and stone bund were practiced. These measures, however, are not enough to control land degradation in the form of soil erosion. Because, in filed survey this paper assured that every year, high amount of eroded material along the shore of the lake deposited. This basically, resulted from the poor wetland management and shortage of sounded soil and water conservation practices on the sloppy ground of the upper watershed area.

4. Conclusion

This paper demonstrated the overall changes of the region by evaluating the water level change trends of Lake Hayq in the previous decades. Water level data analysis, accounting of the water balance of the lake, and data generated from remotely sensed products were used to assess changes that are taking place in the Lake Hayq. Since the 1970s, the water level problem at Lake Hayq was clearly observed and the island completely changed to peninsula and connected with the great landmass at the western edge of the lake through the narrow strip of land or isthmus.

The rate of water reduction was being increased through time. For example, the lake decreased by 472 hectares in four hundred years, where as in the past 30 years the lake decreased by 108 hectares. Based on the previous lake shape, and area model; now, the lake level lowered within 22 meter and almost 5.8 km^2 or 580 hectares surface area of the lake were shattered, as the previous position.

The examined water level data of MoWR (1975 to 2012) of Lake Hayq indicated that there was a serious water level change of the Lake Hayq both long-term and seasonal patterns over time. The current staff gauge location is found 6 meter lower than the benchmark and there is more than 8 meters depth difference between 1969 and 2007 measurements of Lake Hayq maximum depth.

The water balance studies of Lake Hayq was carried out by considering estimates of rainfall directly over the lake, open water evaporation of the lake, surface water extraction and surface runoff. The water balance of Lake Hayq result implied outflow is greater than inflow or input, which is 0.9 million cubic meters water deficit in every year. The accounting of water balance clearly indicated that much amount of water is losing from the Lake

Hayq and the lake is going to be dry land in short period of time.

The satellite image analysis in this study indicated that the distribution of the shrub land, grass land and forest area from the classified images dated 1972, 1986 and 2010 were decreased. From 1972 to 2010; 15.3% of shrub land was disappeared, grassland and forestland areas were decreased by 10.6 %. The equivalent amount of land was converted to agricultural practices especially for the region around the lake area and all the sloping ground area of southern part of the watershed. In addition, approximately 108.4 hectares, which were covered by water, became agricultural land and grass land. The width of isthmus increased from 33 meter, to 108 meter and 163 meter in the year of 1972, 1986 and 2010 LULC change respectively. Therefore, through time the width of isthmus became wider and wider.

Lake Hayq is totally surrounded by agricultural land, grazing land and built up area, there is no doubt that human practices take the lion share in ecological disturbance of the lake. This is indicated through the analysis of buffering zone of the Lake Hayq in 1972, 1986 and 2010 LULC satellite image. In 1972, the farmland activities were not experienced at 30 meter buffer zone of the lake; whereas in 2010 at the same buffering zone, the farmland activities were expanded at 52 % on the periphery of the lake.

In general, this study indicated gradual decrement of water level in the Lake Hayq. This may cause drying of the lake totally at sometime in the future. The LULC change in the area around the lake, higher agricultural practices and diminishing of forest, shrub and grassland can be one of the major reasons for water level decrement. The LULC change with steepness of the slope and erodibility of the soil aggravated erosion, sediment yield and siltation in the watershed area. The second major factors that reduced water level can be imbalance of output and input of the lake. This is caused by drought and rainfall variability. Population pressure can be other factor that come water level reduction. Over pumping surface water of Lake Hayq without a detailed scientific study to irrigated fields, expansion of agricultural land on the periphery area of the lake, the establishment of irrigation schemes at the upper part of the watershed area this might be blocked the contribution of the neighboring basins, an improper use of wetlands for grazing owing to increase sediment deposition connected to the lake, low adoption of soil and water conservation practices, misuse of farm land and deforestation are the major anthropogenic factors that revealed the water level fluctuations of Lake Hayq.

In the light of the above conclusions drawn from the results of the study on evaluation of water level change of Lake Hayq and sustainable use of the lake resource, the following points are outlined as recommendations.

- The expansion of agricultural land at the perimeter of the lake shore should be buffer on the line with this findings and the wetland can be recovered through the environmental protection activities of seedling indigenous plants, riparian vegetations and plantation agriculture.
- Sounded conservation measures through afforestation and soil conservation program are an immediate requirement to decrease the rate of land degradation in the form of soil erosion and sediment yield.
- It is strongly recommended to avoid construction of new high potential water pumping irrigation project since the existing outflow condition is greater than inflow conditions.
- Guidelines should be set by the pertinent body to utilize Lake Hayq water resources for irrigation purposes in regard to restriction and scientific based studies.
- Any plan in relation to lake Hayq should consider the ever increase of population.
- The MoWR taking into account the recommendations on the preparation of establishing the special standard stationary gauge reader for reading water level of Lake Hayq.
- Further studies should be undertaken by researchers, to ascertain the rate of sedimentation and siltation problem.

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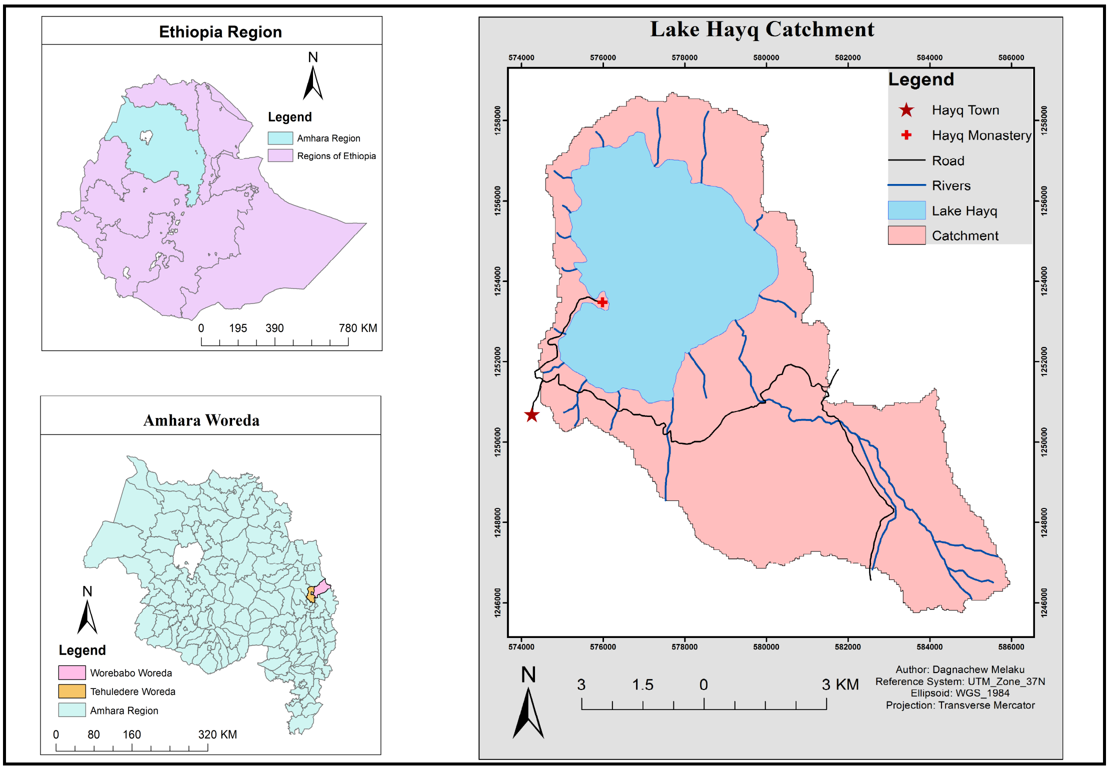
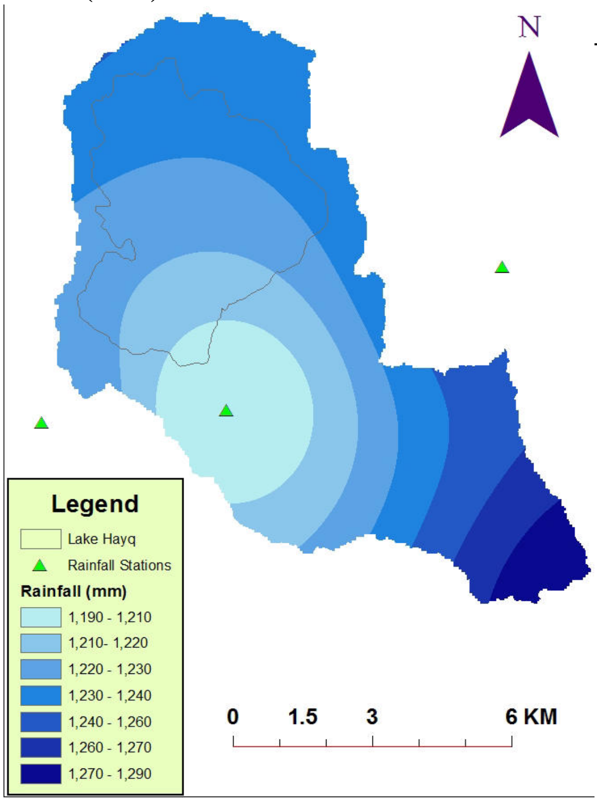


Figure 1: Location map of Lake Hayq in respect to Ethiopia and Amhara regional State



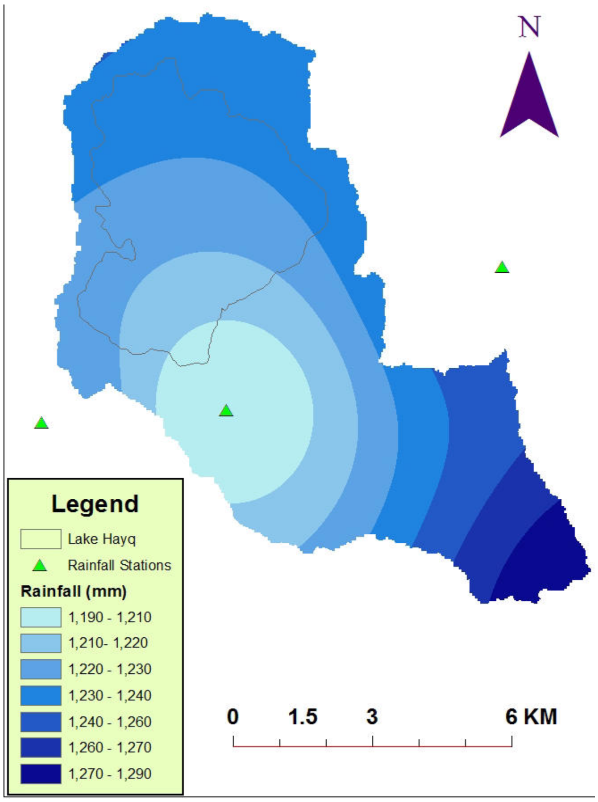


Figure 2: Precipitation map of Lake Hayq watershed area.

Figure 12: Activities of small scale irrigation by local farmers, 2013.

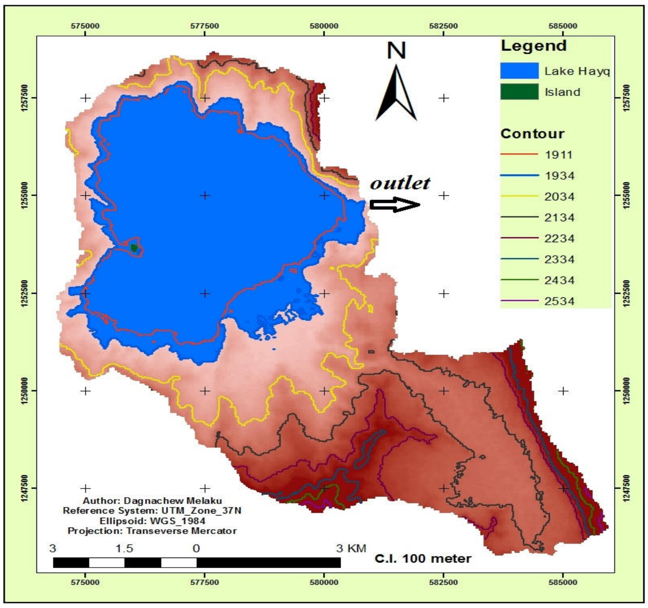


Figure 13: Previous Lake Hayq shape, area and topography model (source; Alvarez, 1540).

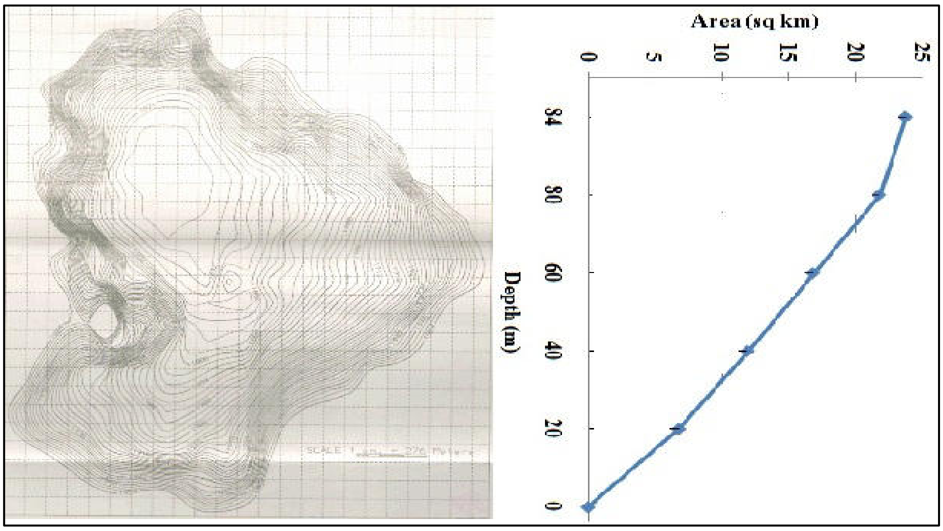


Figure 14: Bathymetric map of Lake Hayq (from Morandini, 1941).

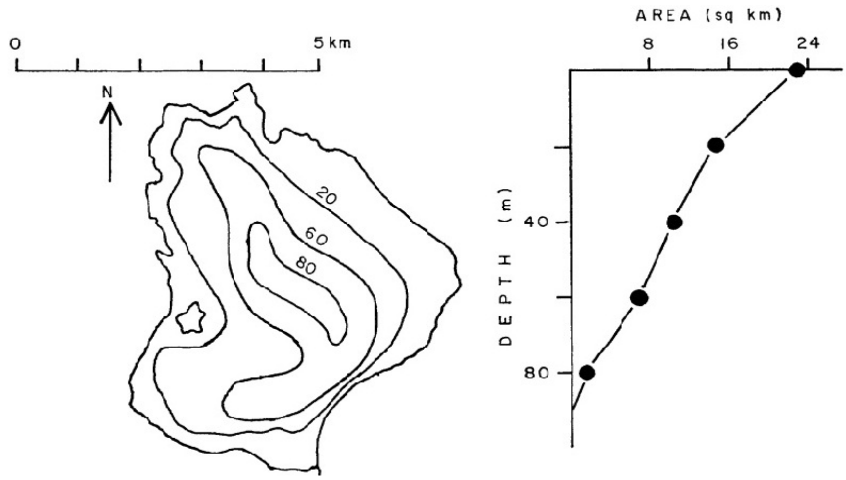


Figure 15: Bathymetric map of Lake Hayq (from MoWR, 2000).

Figure 16: The distance between BM and the current Gauge, 2013.

Figure 17: Different gauges on Lake Hayq at different time, 2013.

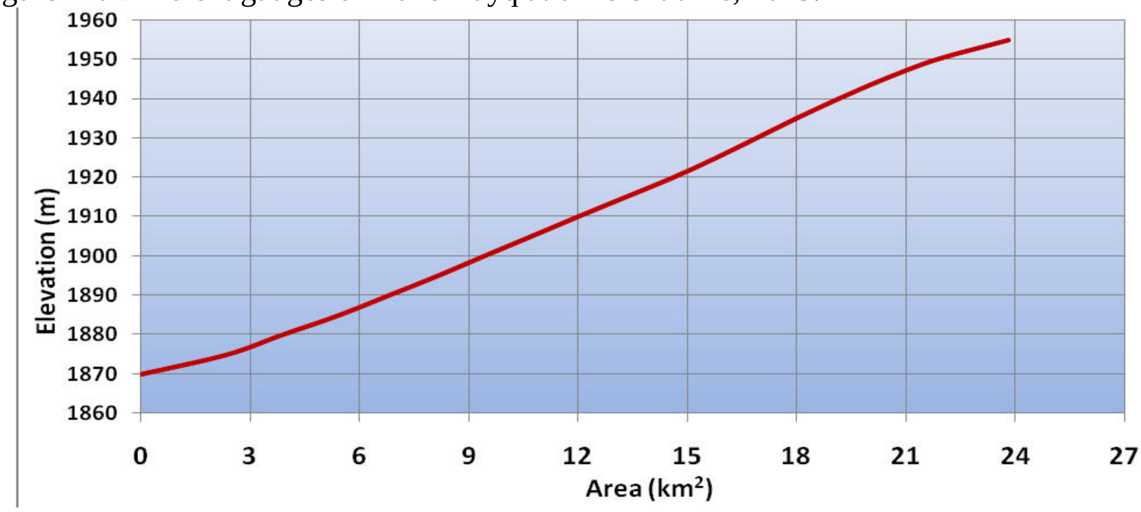


Figure 18: Lake Hayq Elevation area curve (Source; MoWR, 2000).

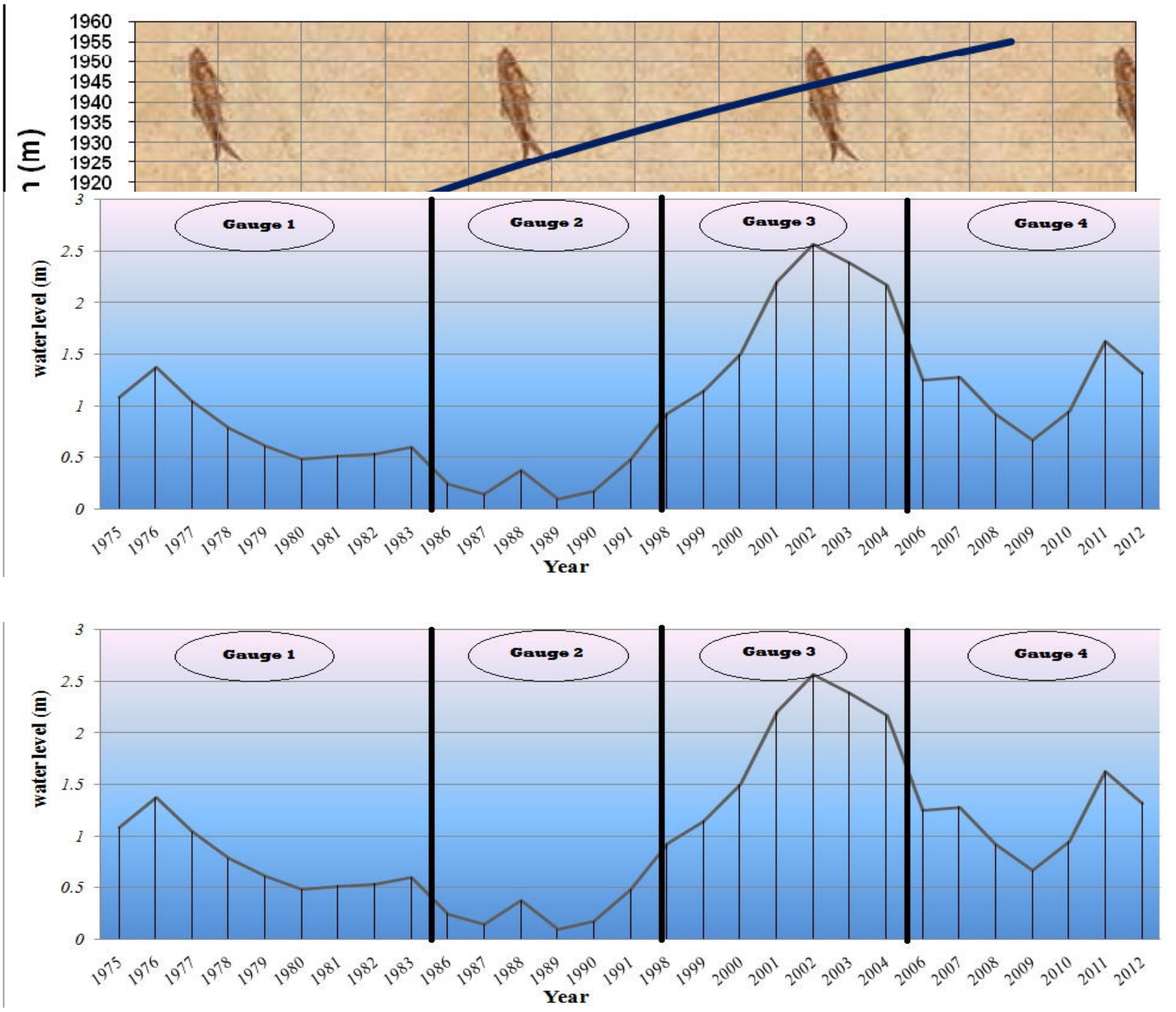


Figure 20: Water level change trend of Lake Hayq (Source; MoWR, 2012).

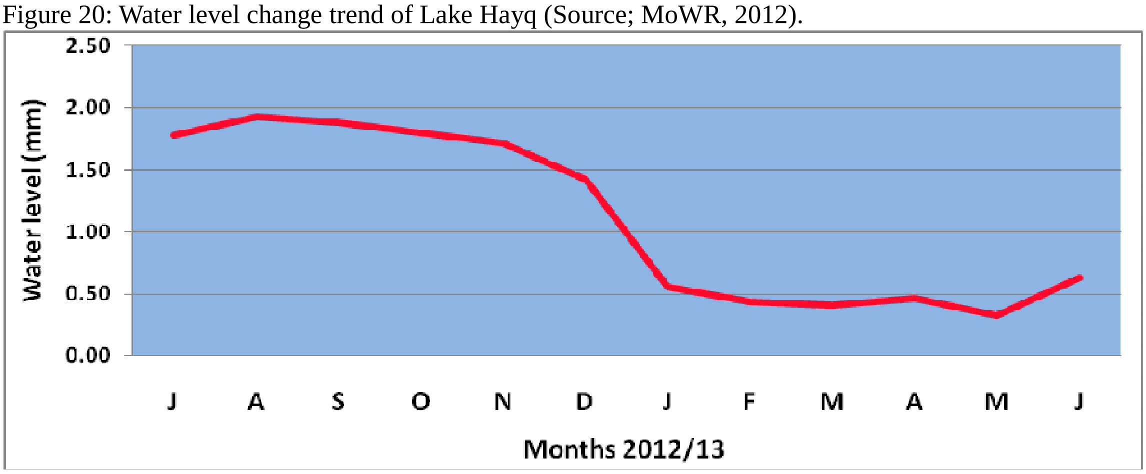


Figure 21 : water level change of Lake Hayq (source; Author, 2012/13).

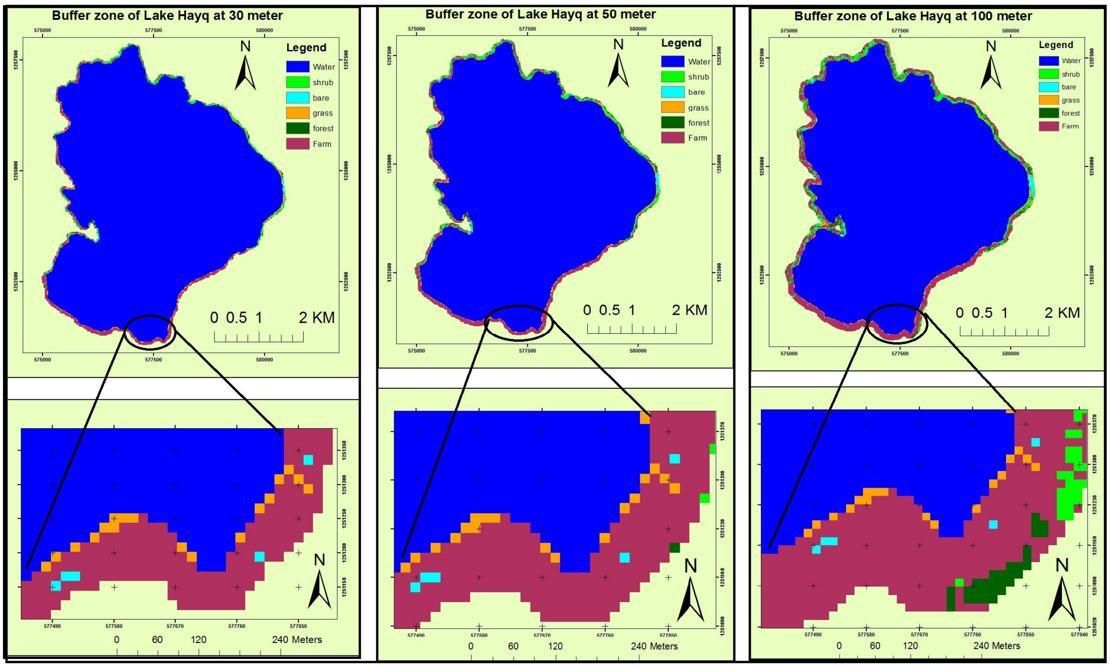


Figure 13: Farmland Practices on the buffer area of Lake Hayq at 30, 50 &100 meter.

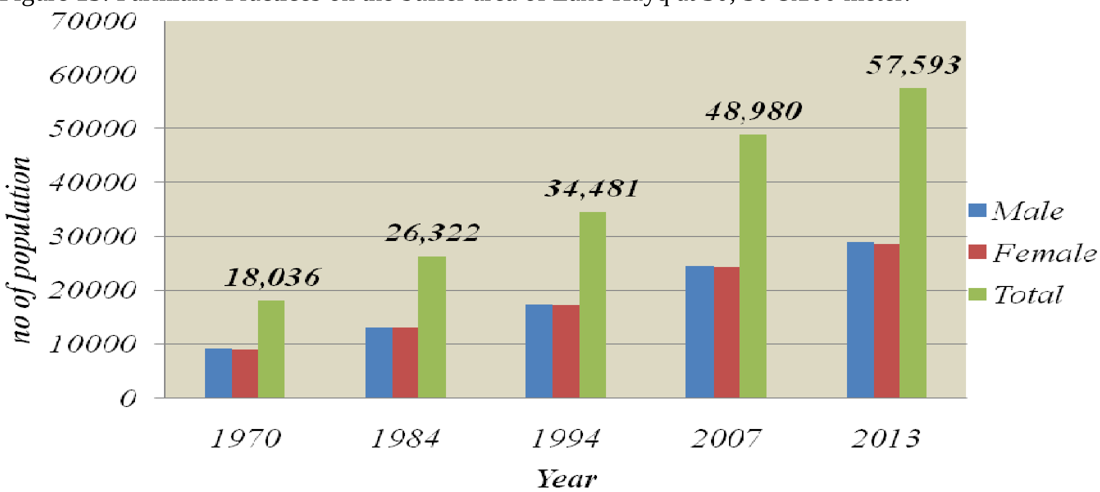


Figure 22: The population growth trend of Lake Hayq watershed area.

Table 1. Datasheet of Mock-up Test

Table 1: Long term water balance of Lake Hayq in (million cubic meter) (1980-2011)

Watershed area (km^2)	lake area (km^2)	*Pw*	*Si*	*Ew*	*So*	*AH*
77	22.8	*28.2*	*20.0*	*46.6*	*2.5*	*-0.9*

Table 2: Morphometry data of Lake Hayq in 1938 (from Morandini, 1941)

Max length (north - south)	6.70 km
Max width (perpendicular to above)	6.0 km
Perimeter	21.70 km
Area	23.2 km^2
Max depth	88.2 m
Ave depth	37.37 m
Ave slope of basin	$3^{\circ}25'$

Table 3: Historical survey of depth analysis at Lake Hayq.

Date/Year/	Max depth (in meter)	lake area (in km^2)	Source
1540	110	28	(ArcGIS model based on; Alvarez, 1540)
1941	88.2	23.2	(Morandini, 1941)
2000	84	24	(MoWR, 2000)
2007	81	22.8	(Molla etal. 2007)

Table 4: Calculated Farmland practices on the buffer area of Lake Hayq (source; LULC)

Buffer area around the lake shore	Agricultural land coverage (in percent)		
	1972	1986	2010
30 meter	0 %	28 %	52 %
50 meter	4 %	38 %	66 %
100 meter	12 %	46 %	81 %