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PROSPECTS AND THREATS OF GROUNDWATER DEVELOPMENT FOR TOWN WATER SUPPLY AND IRRIGATION DEVELOPMENT IN RIFT VALLEY PLAINS

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ABSTRACT

This work presents prospects and threats of groundwater development for town water supply and irrigation development in rift valley plains. The Becho alluvial plain gets recharge from rainfall, floods from dendritic stream networks and groundwater transfers from adjacent basins. Recharge estimation from two base flow separation methods indicated that the plain is getting an annual recharge of 89.8 mm. There are cyclic rain shortages every three to four years. The poor rainfall seasons record nearly half of the best rainfall seasons. Abstraction and water levels in Becho plain are in the region of 25,000 m^3/day and 10 meters, respectively. But these are each less than ten folds of that in the adjacent Akaki basin. Steady and transient state groundwater flow modelling of a basin hosting the Becho and Akaki catchments showed that the former is nearly in steady state while the latter is under excessive mining. Time series of well water level measurements, base flow separation and transient groundwater flow modeling suggest that the Becho plain has potential for motorized irrigation and ground water development under regulated situations. However, in the face of lower transmissivity and storage coefficients, utmost care is needed to minimize propagation of groundwater level decline from adjacent Akaki wellfield.

Contribution/Originality: This study is one of very few studies which have investigated the time series well water evolutions and prospects of multipurpose groundwater development in the Becho catchment.

1. INTRODUCTION

The Becho catchment is located in central Ethiopia on the western edge of the Main Ethiopian Rift (MER) and at upper and western part of Awash River Basin. It is surrounded in the north and north west by Blue Nile River Basin; in the west and south west by Omo_Gibe River Basin, and in the east by Furi and Wechecha mountains range and Melka Kunture Horst. Geographically, the catchment lies between 384986.2 E-465362.7 E (Longitude) and 926709 N-1028270.6 N (latitude). It has an area of 4,553 KM^2. The catchment is constituted by portions of Becho, Ilu, Dawo, Ejere, Welmera, Sebeta Hawas and Tole woredas. As projected from 2015 CSA, the total population in the Becho Plain is around 223,727.

The becho plain has ample land and water resources for irrigation and groundwater development. However, it is annually inundated for several months and poorly drained, which severely hinders agricultural productivity and a comfortable rural life of the farmers in the plain. The plain has huge potentials as one of the drinking water and food supply bases for Addis Ababa. Moreover, the network of rivers and wide expanses of flat-flying land may pioneer agricultural development projects in inundated and poorly drained areas.

In connection with the aim of this study, it is intended to give first-hand information on the groundwater potential of the Becho plain for water supply and irrigation developments. To study these, conceptual modelling of the aquifer systems, recharge estimation, and monthly water level measurements were assessed.

2. SCOPE OF THE STUDY AND SITE DESCRIPTION

2.1. Scope of the Study

Recently, transient ground water flow modeming was conducted in Becho plain and Upper Awash basin. Despite, the low groundwater abstraction conditions, ground water potential, hydrogeological properties and modelling results portrayed that the Becho plain has prospect to support the ongoing irrigation and water supply developments.

Currently, several irrigation and groundwater development projects are ongoing. On top of this, previous studies on irrigation development (GroFutures [1]; Japan International Cooperation Agency [2] and Water Works Design and Supervision Enterprise [3]) and town water supply (Water Works Design and Supervision Enterprise [3]; Water Works Design and Supervision Enterprise [4]; Water Works Design and Supervision Enterprise [5] and Water Works Design and Supervision Enterprise [6]) are all promoting for huge intervention in irrigation and groundwater development. These studies, however, did not worry about the looming competition between town water supply, irrigation development and industrialization as well as the groundwater level depletion scenarios in the adjacent Akaki wellfield.

The objective of this study is, thus, to identify the extent and sizes of the aquifer systems, assess long term and seasonal variation of groundwater tables and review reactions of the aquifers to adjacent wellfield pumping. Time series recharge and abstraction rates (Section 4.1.5 provides summary of water balance and budget for Becho catchment), monthly and long-time groundwater level measurements (Section 4.2 provides evolution of groundwater tables) and transient reactions to excessive pumping in adjacent catchment are collected and reviewed to assess the groundwater potential of the area.

2.2. Site Description

The Becho catchment covers a total area of 4,553 km^2 and is located in the western edge of the Upper Awash Basin which itself is situated at the western edge of the Main Ethiopian Rift Valley. The plain is bounded between 37^0 57' 15.5 E and 38^0 41' 05 E and 8^0 23' 02 N and 9^0 18' 09 N. The southwestern, western, and northern volcanic mountain ranges widely form the watershed divide of the Becho catchment with Omo-Gibe and Blue Nile basins, respectively. The catchment is surrounded by volcanic picks and mountain ranges that form down sloping terrains that drain to the south east towards the rift floors. This gradient favors the occurrence of many springs at different elevation and develops relatively shallow groundwater level in the Becho plain Figure 2.

The landforms of the catchment are the results of different episodes of Cenozoic volcano-tectonics, denudation and later erosion. It is because of these that the catchment is flanked by different size volcanic peaks, mountainous sloppy volcanic formations which favored formation of dense drainage networks.

With regard to the geology of the catchment, it is manifested by Pre-Rift, Syn-Rift and Main Rift Volcanic Units (Assefa [7]; Berhanu [8]; Birhanu [9]; Efrem [10]; Mohr and Zanettin [11]; Tsegaye and Mazarini [12] and Tsegaye, et al. [13]). Hydro-geologically, in this study, these are categorized into two litho-stratigraphic units as pre-rift Ethiopian Volcanic Plateaus and the Main Rift Volcanic Units.

The Pre-Rift units are Upper Oligocene to Late Miocene plateau flood basalts and shield volcanos whereas Main Ethiopian Rift Volcanic is expressed by Late Miocene, Pleistocene to Holocene products of volcanic rocks of welded to partially welded pyroclastic flows with basalt, rhyolite and trachytic lava domes. The rainfall patterns of the study areas are distinguished by two separate seasonal climatic displays: the rainy season which stretches from June to September, contributing much of the annual precipitation and the dry period which covers the month from

October to May with a minimal rainy time in March and April well understood for its inconsistency. The considerable part of the Becho plain is inundated during the period from June to September. This is because the carrying capacity of stream channels, especially at the confluence of Awash river with other tributary streams, is insufficient for discharging flood. Other reasons include the small banks and gentle river bed gradients. Hence, flood water overtops the river banks and flows into flat lying plains causing flooding.

Temperature and rainfall pattern show strong altitudinal dependences. Mean annual temperature is about 9.5 C^0 in the highlands and around 25.8 C^0 in the plains. The average annual rainfall ranges from around 951.4 mm around Tefki and Teji to 1,133.8 mm at Addis Alem Station. Figure 1 displays the location of the study area whereas Table 1 displays annual average precipitation.

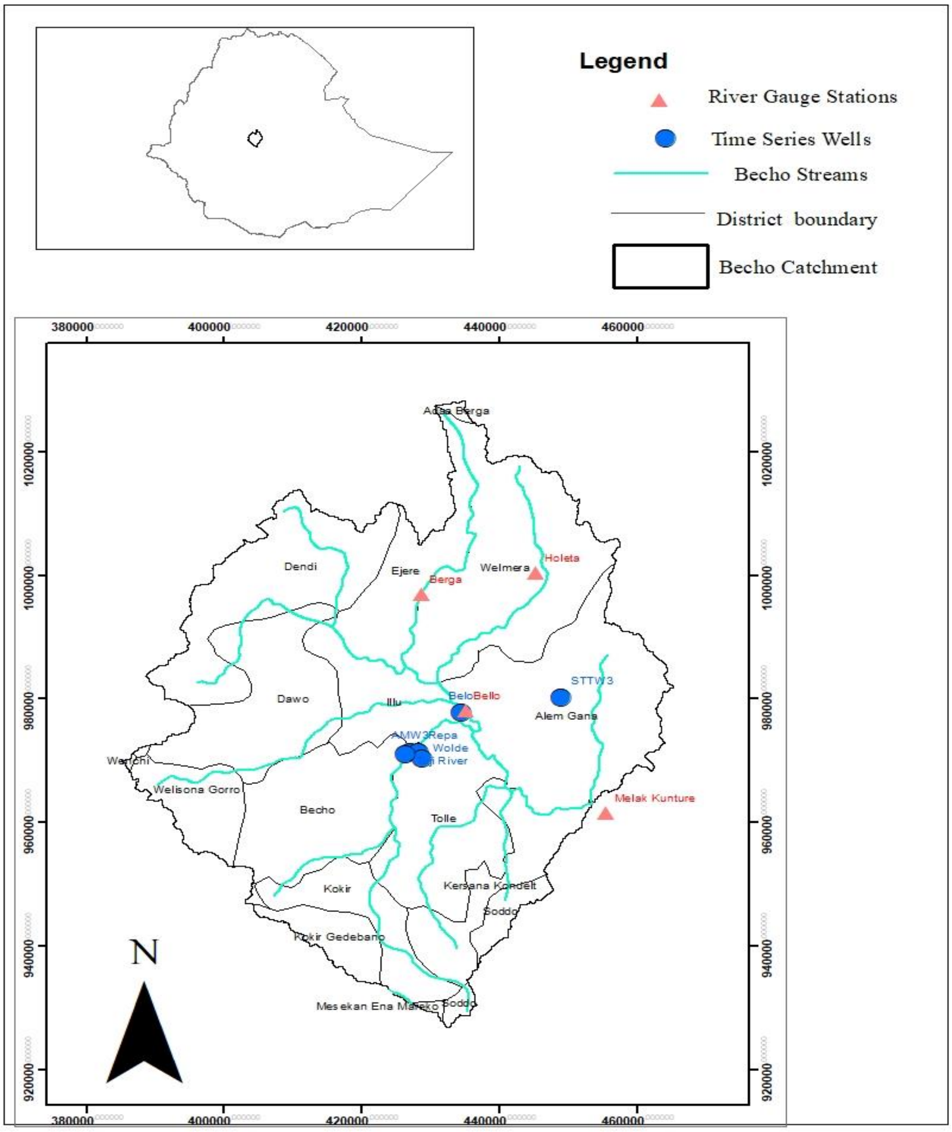

Figure 1. Location map of the study area.

Table 1. Annual rainfall (mm/year) of Becho Catchment.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Ginchi	29.61	25.39	69.46	85.57	86.98	162.82	230.92	239.63	134.63	27.29	11.59	11.59	1115.48
Teji	7.39	13.62	56.67	63.65	87.97	157.02	214.84	213.61	105.72	17.15	11.26	2.51	951.42
Addis Alem	10.59	33.75	85.85	61.32	87.38	150.43	263.61	235.27	142.79	23.19	25.56	14.09	1133.84
Catchment Summary													1066.91

In addition to recharges from precipitation, there are also surface and groundwater influxes from mountain chains to the Becho plain. The Becho catchment comprises both recharging and discharging zones. The promising rainfall and recharge conditions favored presence of perennial streams which finally converge into Awash river before leaving the Becho catchment.

In connection with hydrochemistry, the water in the catchment passes through different hydro-chemical evolutions. Sufficient precipitation and the hydrolysis reaction in the highlands results in silicate dissolution that frees up many of the major cations and anions. The water with these ions infiltrates down by interacting with the different minerals mixing and evolving from acidic water in the highlands to basic and slightly salty water to towards the catchment outlet. This weathering process creates thick and fertile soil mass that suits agriculture in the midland and plain. In general, groundwater evolves from low pH hence recently recharged Ca-HCO_3-type groundwater on the escarpment to Na-HCO_3 rich and rising pH groundwater dominating plain [7].

3. APPROACH AND METHODOLOGY

Several climatic, metrological, hydrological, hydrogeological, and geological information were collected and observations made to develop the preliminary conceptual view of the Becho catchment. Some of the results of the previous studies on time series recharge assessment [14] and the ongoing transient groundwater flow modeling [7] were used. Moreover, temporal groundwater level data collection Figure 4 was done to assess the temporal variability of the groundwater level. The temporal groundwater level monitoring comprised monthly well water level measurement conducted from July 2018 to June 2019 on wells which represented the existing wells in the catchment. The data gathered on groundwater level, recharge, aquifer property and thickness, hydrogeology, study area geometry, aquifer boundary and flow directions helped to prepare the conceptual model and cross-sections across the catchment Figure 3. The study area boundaries were delineated by Arc SWAT watershed delineator. Similarly, cross-section surface slopes were prepared by extracting XZ profile data from the 30m digital elevation model extracted from SRTM Digital Elevation Model. Reaction of water tables to transient stresses largely applied on Akaki well field, which is adjacent to Becho catchment, is assessed through transient groundwater flow modeling. In general, to assist the study, the aquifer systems of the Becho catchment are conceptualized, monthly water level and abstraction rates are collected. Some results of the transient groundwater flow modelling are included to develop the study.

4. RESULTS AND ANALYSIS

4.1. Aquifer Conceptualization

A conceptual simplified representation of the aquifer systems of the Becho catchment was prepared to understand the hydrogeological units and flow systems of the groundwater [15]. The conceptual model included boundary conditions, cross-sections of the aquifer system, compiled and analysed aquifer properties, water level and flow system and other study area features.

4.1.1. Study Area Delineation

The study area is differentiated from adjacent basins by its distinct watershed. The Becho catchment has clear topographic highs that separate it from adjacent Blue Nile, Ghibe, and Rift Valley basins. The watershed boundaries were delineated by using Arc SWAT Watershed delineator by defining streams, stream networks, and stream outlets.

The general groundwater flow direction for Becho catchment is from west and north west to east. There is a general understanding that groundwater is entering into Becho catchment from adjacent Blue Nile basin Andarge [16]; Behailu [17]; Seifu, et al. [18]; Tilahun [19] and Water Works Design and Supervision Enterprise [3]. Moreover, groundwater enters the conceptual model areas as base flow and outflows at eastern boundaries.

4.1.2. Water Bearing Formations of the Study Area

It is assumed that there are hydrogeological windows, through faults and fractures, or general rift-ward dipping. These windows or dipping are expected to channel groundwater from the adjacent Blue Nile Basin to portion of the Becho catchment Andarge [16]; Seifu, et al. [18]; Tilahun [19] and Water Works Design and Supervision Enterprise [3]. Apart from these, in this study, the stratigraphic units of the study area are geologically divided into two main groups [7]. The first group is the Upper Oligocene to Lower Miocene Trap Series Basalt and Trachyte formations [11] which are sometimes termed as the uplifted Ethiopian Volcanic Plateau Tsegaye, et al. [13]. This unit forms the lower volcanic aquifer of the conceptual model Figure 3. The formation is thicker at the north section of the study area otherwise it steeply dips into the rift floor.

It is manifested by columnar basalts, weathered and fractured basalts, trachyte, ignimbrites and rhyolites. Transmissivity ranges are wide (1 to 266 m2/day) largely due to heterogeneity of the aquifer system and lineament density Andarge [16] and Tilahun [19]. Moreover, groundwater tables in this formation reaches up to 50 (towards the catchment boundary depending on geomorphology and fracturing).

The Late Miocene (12 Ma) to recent age upper volcanic sequence Tsegaye, et al. [13] is considered as the second aquifer group and forms the upper aquifers of the conceptual model Figure 3. This category consists of wide range of aquifers. The main water bearing formations are ignimbrite and tuff formations which are underlain by basaltic layers. From west to east (to the rift floor), the basalt gradually thins out and pyroclastic rocks (ignimbrite and tuff) gradually thicken. Thin paleo-sol layers between successive volcanic episodes and contact zones between different rocks also form water bearing zones.

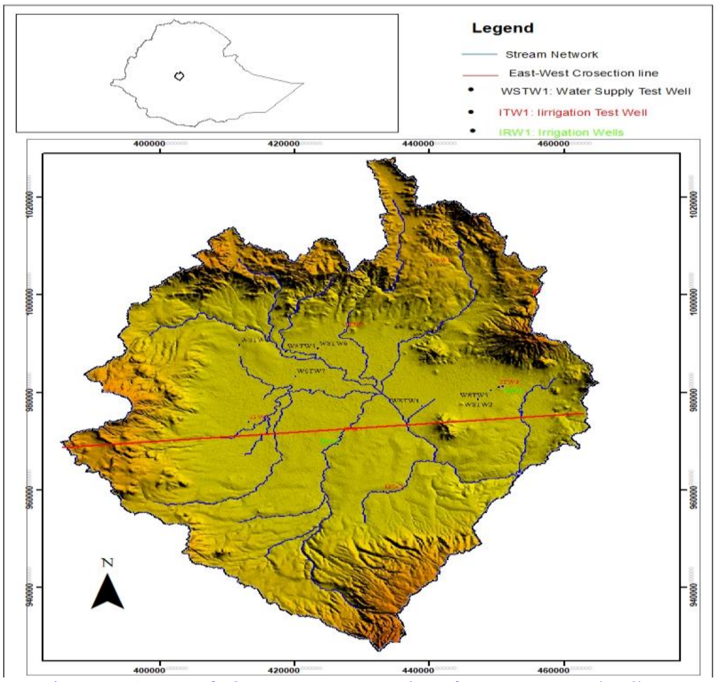

Figure 2. Geomorphology, stream network, and E-W cross section line.

Shallow and hand dug wells are almost feasible on the flood plain areas. The groundwater level in Becho plains are below 10 meters. Towards the slops and hills, feasible sites are located along promising geomorphology, geologic structure and stream banks. Despite the considerable drawdown, majority of the wells have good transmissivity (17 to 120 m^2/day) although this is much lower than the nearby Akaki catchment which is on average 1,468 m^2/day). The Figure 2 portrays the geomorphology, stream network, and E-W cross section line of the study area.

4.1.3. Stratigraphy and Cross-Section

Data from tens of wells with depths as deep as 440 meters are used in preparing hydro-stratigraphic units explained under Section 4.1.2 (water bearing formations and stratigraphic units). Additional previous cross-sections done by Tsegaye, et al. [13] and Geological Survey of Ethiopia Efrem [10] and Tadese [20] for different parts of Upper Awash Basin are used to develop the interpretation. Among the several cross-sections done during this study, the main alignment which portrays majority of the features of the basins is given below in Figure 3.

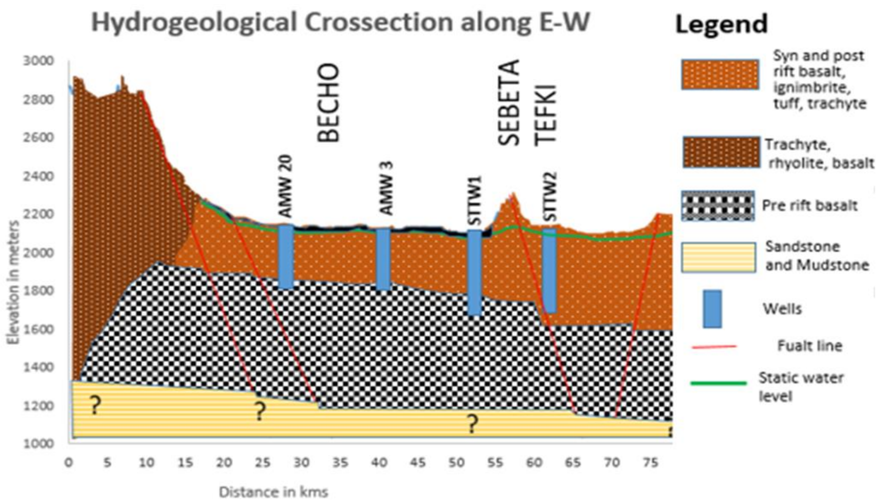

Figure 3. Hydro-stratigraphic cross-section of the Becho catchment from east to west.

4.1.4. Hydraulic Properties

Transmissivities of the different aquifers are given under Section 4.1.2 (transmissivities of water bearing formations). Hydraulic conductivities are the function of transmissivity and aquifer thickness, hence the values given in the mentioned section denote hydraulic conductivities. As per the information from the five district water offices, there are more than 1,000 hand dug wells of depth between 5 to 15 meters. Most of these wells are being used for domestic water supply. A few others supplement horticulture. Moreover, there are more than 60 drilled shallow wells of depth between 40 to 120 meters largely providing service for rural towns and district centres. Apart from these, in the last 15 years around 20 deep wells of depth between 350 to 450 meters are drilled for irrigation and test wells for Addis Ababa water supply. As per the information from these wells, hydraulic conductivity does not show significant change with depth Water Works Design and Supervision Enterprise [3]; Water Works Design and Supervision Enterprise [4]; Water Works Design and Supervision Enterprise [5] and Water Works Design and Supervision Enterprise [6]. With regard to storage terms, majority of the wells were pump tested without observation wells hence it is difficult to get sufficient values of specific yield and storage coefficient. Storage terms account for the rate of amount of water stored or released from aquifer due to changes in hydraulic heads Harbaugh, et al. [21]. On the other hand, due to the interconnectedness of the aquifers, it is difficult to categorize aquifers into confined and unconfined layers. In such conditions, specific yield and storage coefficient are interchangeably used Anderson, et al. [22]; Harbaugh, et al. [21] and Waterloo Hydrogeologic [23]. In general, based on field data and previous studies, the storage coefficient values range from 0.15% and 0.25% [3-5]. This is much lower than the adjacent Akaki catchment which exhibit storage coefficient between 0.6% to 2%.

4.1.5. Water Balance and Budget

A water balance estimation implies computation of the volume of water both entering and living the model area and includes the flow terms like river flow, fluxes, recharge, well abstractions, and flow across boundaries. Several water balance calculations were made for the same model area by numerous authors. Recent ones include [24]-Table 2.

Table 2. Summary of water budget for the Becho catchment [24].

Flow term	In (m³/day)	Out (m³/day)	In-out (m³/day)
Wells	0.00 E +00	9.83 E + 04	-9.83 E + 04
Recharge	1.07 E + 06	0.00 E + 00	-1.07 E + 06
River leakage	3.39 E + 05	1.87 E + 06	-1.53 E + 06
Head dep bounds	6.83 E+ 05	1.28 E+ 05	5.54 E + 05
Drains	0.00 E+ 00	6.48 E + 01	-6.48 E + 01
Sum	2.09 E + 06	2.09 E + 06	9.38 E + 01
Discrepancy [%]	0.00		

Note: 1 E +05 implies 1 x 10^5.

Overall discharge and recharge estimation was made based on time series recharge and discharge measurements conducted for the indicated months (Table 3). The recharge values were the average of two base flow separation methods: Hydrograph Separation and TIMES PLOT. Well abstraction was calculated based on dry and wet season average pumping rates.

4.2. Evolution of Groundwater Tables

Times series of groundwater tables for two boreholes and four shallow wells were collected in this study in 20018 and 2019. Moreover, there are groundwater tables measured during pumping test. Table 3 provides time series recharge and discharge measurements.

Table 3. Temporal recharge and discharge values for Becho catchment.

Month	Becho Catchment	
	Recharge (mm/month)	Well discharge (M³/day)
January	1.02	31063
February	0.79	
March	0.73	
April	0.93	
May	1.17	
June	4.12	
July	17.59	20708
August	29.54	
September	23.11	
October	7.70	
November	1.90	
December	1.19	
Total	89.78	

Static water tables taken from six wells in 2007 and another static water tables taken from five wells in 2019 showed only one-meter decline over the 12 years' period. Rather more water level changes are observed between dry and wet seasons Figure 4. The unusual observation in the figure is the decline of water tables at the pick of the rainy season (between June and September). Groundwater tables in the area and its vicinities are expected to be lower around April and pick around August. However, the opposite is happening. This may show that the recharge to the area is not directly governed by rainfall but from upstream highlands.

Nonetheless, as compared to water levels in nearby catchment (Akaki), the Becho area is nearly in steady state. Some of the major reasons are the low rate of abstraction and the high rate of recharge. Nearly all of the streams in the catchment flow to the centre of the basin Figure 2.

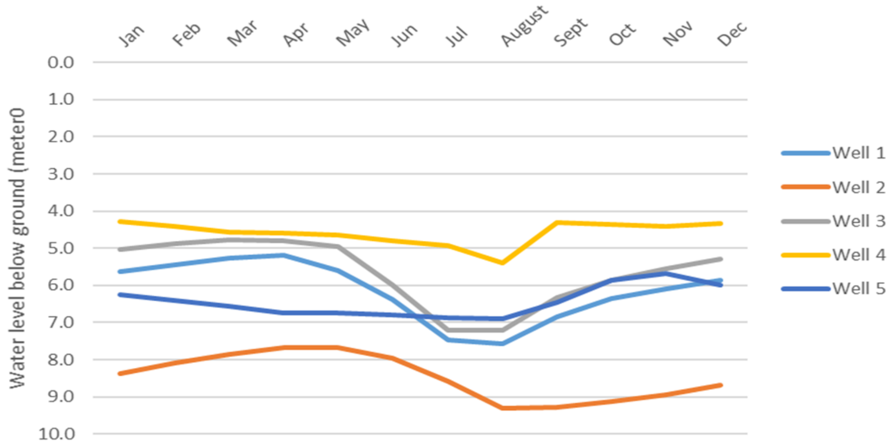

Figure 4. Time series of water levels (deep and shallow wells) in Becho area.

Figure 4 portrays only two seasons (one year) water level evolutions. To observe the complete picture of recurrent well water level fluctuations over prolonged climatic and metrological conditions, several years' water level data are needed. The following river flow data is processed by base flow separation methods (Hydrograph separation and TIMES PLOT) in an attempt to at least display several episodes of surface water level fluctuations Figure 5. The figure exhibits evolution of base flow over the rives in Becho between 1991 and 2004.

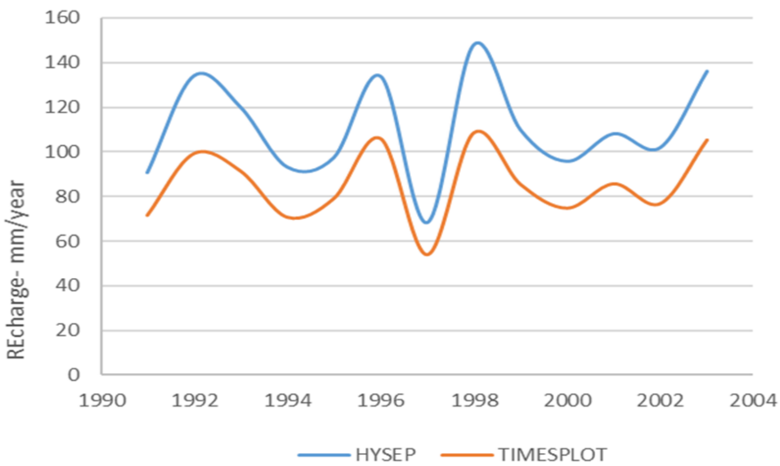

Figure 5. Evolution of base flow over the rives in Becho Catchment (mm/year).

As per the figure, the years 1994, 1997 and 2000 might show lower recharges and hence lower rainfall in the catchment. These years might have resulted in drought or reduced rainfall in other areas. However, in Becho catchment reduced rainfall means reduced flooding to the Becho plain.

In addition to the above time series of groundwater level and base flow separation methods, transient groundwater flow modeling was done on Upper Awash basin which consists of the Becho catchment.

Even though Akaki well field and Becho plain are adjacent and share general head boundaries in the Upper Awash Basin, the behavior of the groundwater table in the two areas is very much different while still in the same model. While the Akaki well field is displaying a drawdown of 300.9 meter at the end of the third scenario (Abstraction rate of 2,180,300 m^3/day), the Becho plain is exhibiting almost no drawdown still in the same scenario. This might be due to the magnitude of the recharging conditions in the Becho, high abstraction in Akaki well field area and the poor permeable Wechecha and Furi mountain and the Melka Kunture horst volcanic ranges that separate the Becho plain from the Akaki well field. Table 4 presents the evolution of drawdowns for different abstraction rates in Becho plain over 15 years.

Table 4. Evolution of drawdown in Becho plain for different abstraction rates over 15 years.

Simulation Years	Scenario 1	Scenario 2	Scenario 3
2019	-34.50	-32.61	-28.81
2020	-32.07	-27.81	-19.19
2021	-31.59	-26.37	-14.98
2022	-30.35	-24.64	-12.38
2023	-29.21	-23.14	-10.49
2024	-28.26	-21.99	-9.14
2025	-27.46	-21.09	-7.79
2026	-26.79	-20.35	-6.81
2027	-26.26	-19.73	-6.12
2028	-25.86	-19.24	-5.49
2029	-25.46	-18.84	-5.63
2030	-25.19	-18.63	-5.58
2031	-24.94	-18.38	-4.88
2032	-21.30	-14.36	-4.30
2033	-24.50	-17.78	-4.05
Average	-27.58	-21.67	-9.71

Thus, time series of well water level fluctuations, base flow separation and transient groundwater flow modeling suggest that the Becho plain has potential for motorized irrigation and ground water development under regulated situations. However, in the face of lower transmissivity and storage coefficients as compared to the adjacent Akaki basin, utmost care is needed to minimize propagation of groundwater level decline from adjacent Akaki wellfield. Figure 6 presents the evolution of drawdowns for different abstraction rates in Becho plain over 15 years.

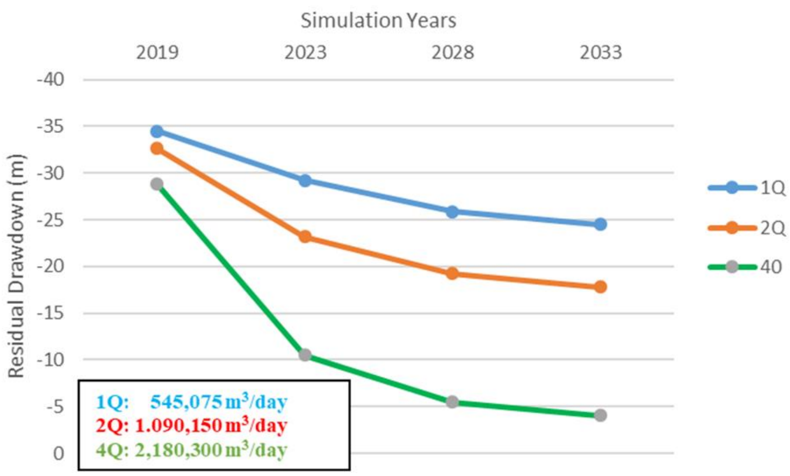

Figure 6. Drawdown evolution in Becho plain in upper awash basin (15 years).

The relatively low hydraulic conductivity values, the high drawdown and the current low abstraction rate in Becho plain means there might be fast groundwater level decline in times of high abstraction as compared to the Akaki well field. Table 5 displays average water levels taken during pumping tests and monitoring measurements as well as drawdowns during pumping test.

Table 5. Average groundwater levels in the Akaki and Becho well field areas.

Well Field	Static Water Level during pumping test (meter)	Static Water Level in Well Monitoring (meter)	Draw Down during pumping test (meter)
Becho plain	7.61	5.65	58.73
Akaki Well field	48.41*	98.62**	96.37

Note: From * 2009 to 2013, ** 2018-2019.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The shallow groundwater table, the high recharge and the water quality (Ca-HCO3 and Na-HCO3 type) are conducive potentials for groundwater and irrigation developments under regulated operation.

However, the catchment is densely populated and industrialization is booming increasing the demand for water. Moreover, despite the promising groundwater potentials, transmissivity and storage coefficient are 1/12 and half, respectively, of the Akaki wellfield.

The conceptual model shows that there are some local poorly permeable and flow barrier volcanic terrains and peaks inside and along the boundaries of the basin. The existing aquifers are sometimes interrupted by these barriers. Even Akaki well field, which is probably the most water bearing area in the Upper Awash basin, is bounded by poorly permeable ridges and hence excessive pumping may influence boundaries. In general, future excessive pumping may impact the regional groundwater table and water level decline in Akaki wellfield may propagate to the nearby Becho wellfield.

Several decades ago, the well fields and pocket areas in Akaki catchment were considered as inexhaustible groundwater sources. However, now they are showing sharp decline. This scenario may replicate to Becho area unless regulated utilization is outlined. As indicated under Sections 4.1.2 (water bearing formations and stratigraphic units) and 4.1.4 (hydraulic properties), the Becho plain has high drawdown, less transmissivity and storage values as compared to Akaki well field, hence it may be highly sensitive for an excessive abstraction.

5.2. Recommendation

There are ambitious groundwater development programs both for water supply and irrigation in the Becho plain. These have to be implemented with regulated groundwater use.

Except short term project based water level measurements, there are no continuous groundwater level monitoring system. Therefore, permanent well water monitoring system shall be established. Well siting and spacing has to be regulated and determined based on the characteristics of the aquifers. The monitoring system may also help understand whether the decline in the nearby Akaki catchment is propagating to the Becho wellfield area.

There are ongoing urbanizations and industrializations in Becho plain, these may be threats to pollution especially to the shallow groundwater, hence precautions must be made so as not to further pollute the resource.

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Authors' Contributions: All authors contributed equally to the conception and design of the study.

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