GIS BASED IRRIGATION SUITABILITY ANALYSIS
(A CASE STUDY OF ABAYA-CHAMO BASIN, SOUTHERN RIFT VALLEY OF ETHIOPIA)

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Abstract

The existing data are captured on a GIS-based approach. The investigation includes data like topography, climate, soil, land use pattern, water availability, agricultural practices, investment costs and socio-economic practices. Furthermore
the irrigation suitability criteria are defined based on these variables.

A Digital Elevation Models (DEMs) digitized basically on the contour-map is developed to investigate the terrain feature of the basin. Accordingly, variation in elevation as well as in slope is evaluated so that appropriate method of irrigation has been suggested.
With the purpose to evaluate units for irrigation suitability stream network are characterized and soil types as well as land use are mapped. Crop development with respect to the prevailing conditions are integrated within this capture. Integrating all the aggregate suitability variables, the potential capacity of irrigable land is identified and mapped as well.
The capacity of low flow as well as 80%, 90% and 95% time of exceedance flow of the available surface water in the respective sub basins is estimated. The area that can be irrigated with this flow is computed for the selected cropping pattern. To maximize the extent of irrigable land storage requirement with respect to different flow reliability level is estimated.

1 Introduction

Population of Ethiopia is largely rural and depends on agriculture for their livelihoods. But agricultural production has not kept pace with population growth leading to sever chronic malnutrition and hunger, and periodic crises induced by drought.
Despite irrigation potential estimated about 3.7 million hectare, only about 190,000 ha (5.3% of the potential) is currently under irrigation which plays insignificant role in the country's agricultural production. Thus to bring food security in the national as well as in house hold level, improvement and expansion of irrigated agriculture must be resorted.

Appropriate management and selection of applicable irrigation method is a prerequisite for wise utilization of scarce physical resources, land and water. To ensure adequate management and design of a particular irrigation system, a well-developed and suitable database is quite important. Thus it should be able to deal with spatially and temporally varying factors affecting the system.
The present study concentrates on qualitative as well as quantitative assessment of the existing physical resources those as land and water with respect to its suitability for irrigation. Furthermore this will be supported by development of a suitability database that would help for further investigation on the area.

The soil, terrain feature (DEM and its derivatives) and land use classification criteria are the basis used to define the suitability. With this respect, the Geographic Information System (GIS) facilities were extensively used. Irrigation potential for the basin on water potential has been investigated in Seleshi (2000). This study improves on that by including land and soil potential and suitability and using water potential scenarios as well.

2 Objective of the study

The main objective of this paper is to provide GIS based irrigation suitability criteria and to assess the natural resources of land and surface water for irrigation with specific objective of:

- Providing an integrated, geo-referenced irrigation suitability database that can be used for identifying potential irrigation investment opportunities with GIS-based approach.
- To map existing and potential identified irrigable areas based on the soil, terrain feature and surface water availability in the basin.
- To estimate potentially usable available physical resources; land and water for irrigation and suggest techniques to be used to compromise between the two.
- To point out appropriate irrigation methods (surface, overhead, pumped irrigation or semi-gravity), which suit particular condition based on the data, obtained.

3 Data and methodology

The study area tries to cover major perennial rivers in Abaya- Chamo sub basin; even though a number of intermittent streams are available in the basin. ETo as well as CWR estimation is made for selected climatic stations and agricultural farms. Run off & low flow potential of the streams is computed for major rivers in the basin. Dominant soil and land use/cover units are considered for the present study.

3.1 Input data and Materials used

After topographic map, soil map, climatic data, and hydrological data have been collected from various sources, further analysis is performed. However, the available data sources are not extensive and thus the study is made under limited data situation. Figure 2.1 shows the location of data measuring stations for meteorology and hydrology information. The materials used include: Softwares: GIS Software, CROPWAT4.3, AUTOCAD 2002; Hard copies of topographical, soil, and land use maps.

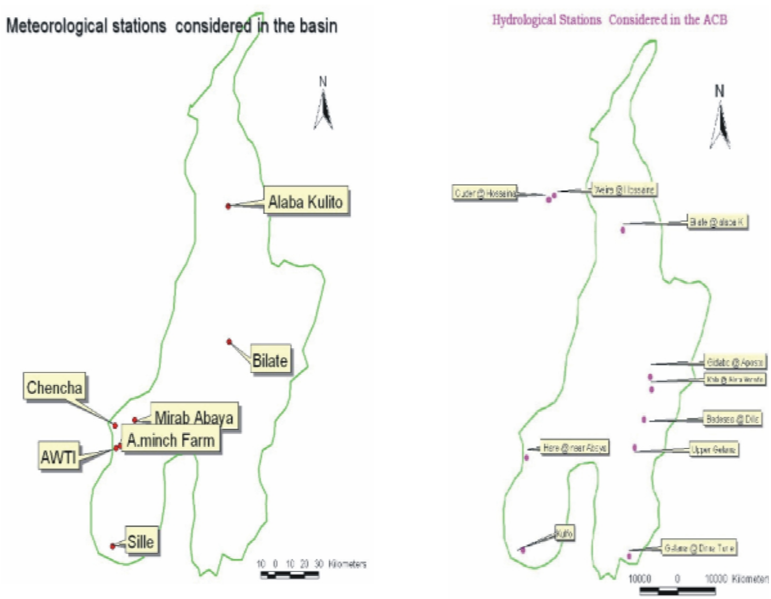

Figure 2.1 Meteorological and hydrological stations considered in the Basin

3.2. Methodology

3.2.1 Estimation of ETo, Crop water requirement and Available low flow

Different methods have been developed and being in use over the last half dozen of decades to estimate reference crop evapotranspiration with respect to the available data. Each of them were subjected to local calibration and limited to global validity. But the Penman-Monteith-method that combines the energy balance and mass transfer equation is commonly recommended.

The Penman-Monteith form of the combination equation is:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

Where

R_n is the net radiation,
G is the soil heat flux,
(e_s - e_a) represents the vapour pressure deficit of the air
P_a is the mean air density at constant pressure
c_p is the specific heat of the air,
Δ represents the slope of the saturation vapour pressure temperature relationship,
γ is the psychometric constant,
r_s and r_a are the (bulk) surface and aerodynamic resistances

The estimation of ETo for selected climatic stations is made available by using the CROPWATW4.3 version. In some cases Haregreaves method is used. This equation is one of the empirical equations that have been used in estimating ETo where the available data is only of temperature. The equation is

$$ETo = 0.0023 * So\ \delta_T\ (T+17.8)$$

Where So = the water equivalent of extra terrestrial radiation in mm/day
T = the temperature in ^oC
δ_T = the difference between mean monthly maximum and mean monthly minimum temperatures.

This equation has been shown at least reasonable estimates of reference crop evapotranspiration (Maidment, D 1992).

A crop water requirement for selected crops is estimated using CROPWAT4.3 for windows. It uses monthly data to estimate evapotranspiration. Monthly rainfall magnitude is interpolated for each month into daily values.

In addition to climatic data, crop and soil data of the area under consideration is provided as input data. The cropping pattern is selected in that way to fit with the local cropping calendar. The respective crop coefficient for the initial mid and let seasons is identified based on the FAO guidelines. The intermediate Kc values were linearly interpolated between the pre-identified Kc values for different stages.

Thus the crop evapotranspiration demand is calculated as: ETc = ETo *Kc mm/period

The crop water requirement is estimated taking care of the rainy seasons. Effective rain fall is determined by the SCS method in the program and deducted from the ETc value.

$$CWR = ETc - P_{eff}, \text{ and } NIWR = CWR * A_{crop} \text{ mm/period}$$

3.2.2 Developing DEMs and Derivatives

The Digital Elevation Models (DEMs) are point elevation data stored in digital computer files. These data consists of x, y grid locations and point elevation or z variables. They are generated in a variety of ways for a different map resolutions or scales. The point elevation data are very useful as an input to the GIS. The data can further be processed to yield important derivative products such as slope, aspect, flow accumulation, flow direction, curvature, etc.. These data have been derived and used for the study area. Figure 2.2 shows a derived contour map of the basin based on the DEM.

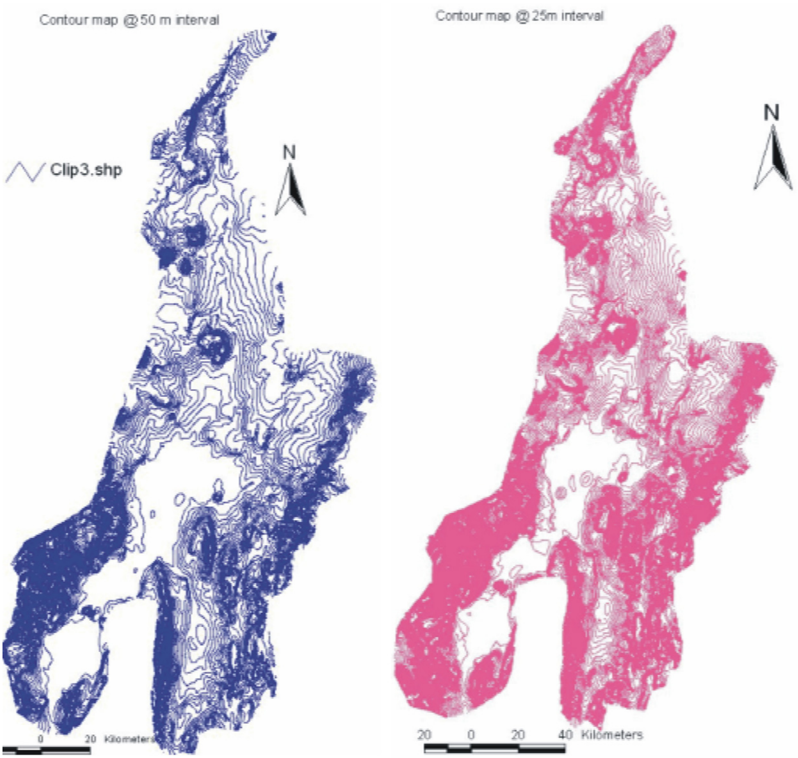

Figure 2.2 Contour map of ACB @ 50m and 25m contour interval

3.2.3 Interpretation of soil and land use data

The basin is characterized by diversified geomorphology and soil patterns. However, the identification of representative soil textures and their physical as well as chemical properties is based on the FAO/ UNDP's classification. To this end, a soil map which is developed from 1:250,000 scale topographical maps to the scale of 1:1,000,000 is reviewed and mapped.

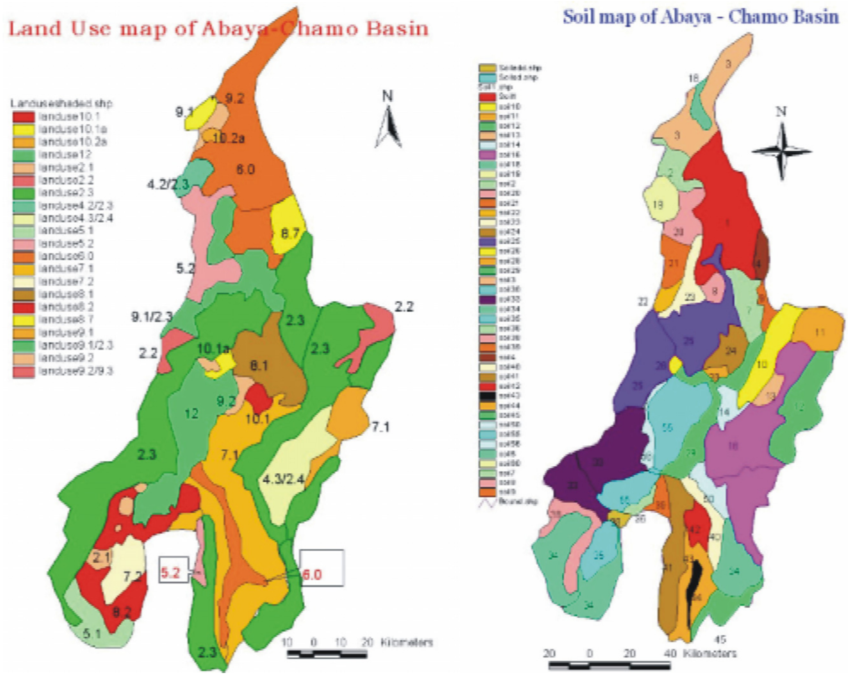

Figure 2.3 GIS Based Soil and Land use map of Abaya- Chamo basin

Identification of potential irrigable sites

Qualitative land evaluation for irrigation is generally based on interpretation of physical characteristics. The most important parameters are slope, soil, land use and the available water resources and its quality.

In evaluating the soil suitability, the criteria identified are soil drainage class, soil texture, soil depth, and salinity /alkalinity hazard of the soil. Furthermore the presence of important minerals such as phosphorus are basic. Slope classification is assumed to be suitable for surface irrigation if it is less than 10%. In other areas where the soil is suitable and water is available slopes up to 20 -30% can be irrigated.

This irrigation depends on water availability in growing seasons or on water storage mechanisms to be pumped by sprinkler or drip systems. Hence these areas are also considered to be suitable for irrigation; in fact the selection between the two is based on the soil texture and other factors.

Table 3.1 Soil suitability criteria set for the present study

Criteria for appraisal	condition	Range of the criteria
Topography: slope	Optimum	< 10%
Drainage	Optimum Marginal	Well drained (W) Moderately well drained
Texture	Optimum	Loam, silty clay, clay loam, silty loam
Soil depth	Optimum Marginal	> 100cm < 50cm
Calcium carbonate	Optimum Marginal	< 30% 30-60%
salinity	Optimum Marginal	< 8 mmhos/cm 8-16 mmhos/cm
Alkalinity	Optimum Marginal	< 15 ESP* 15-30 ESP

*ESP = exchangeable sodium percentage

Potentially irrigable areas were identified based on the aforementioned suitability criteria. To this end, the soil, terrain feature (slope), land use, climate and other factors that controls crop development such as need of agricultural input and erosion hazard are also included. The basin has no recorded data on ground water level fluctuation. A couple of investigations done near Arba Minch area prove ground water flow will not affect crop growth unless excessive application of irrigation water is resorted ground water. Hailay (1995) indicated patches in Sille area of abandoned irrigable land due to water logging as consequence of excessive irrigation water application.

Approximately 0.1Mha of land, which is nearly equal to 5.5% of the basin area, is identified as potentially irrigable. So surface-gravity as well as semi- gravity are irrigable over head methods of irrigation with limited constraints. These constraints can be improved with appropriate water management, soil amendments, and provisions of pumped system to irrigate moderately slopping up lands. The existing as well as potentially irrigable areas are mapped and presented below.

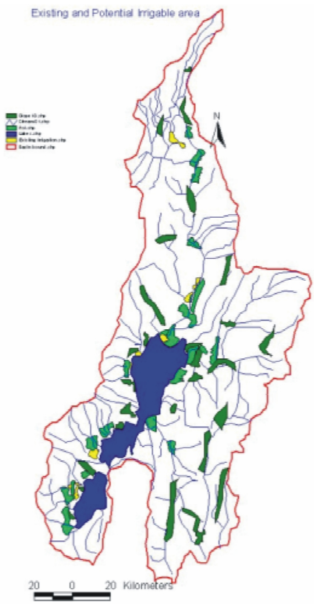

Figure 2.4 Existing and Potential irrigable area identified in the basin

3.3. Water resources availability and Scenario Development under Existing water Resources Condition

Estimated potentially irrigable area is compared to the available minimum flow and different level of percentage exceedance of the river. The available minimum flow of Bilate River is able to irrigate about 76 ha of land during a single irrigation water application time. This is so by maintaining about 25% of the flow for the down stream ecological balance.

Following same argument, the Hare, Kulifo and Sille rivers low flow can irrigate 77 ha, 2.0 ha and 1.0 ha of land during a single application in the critical month. The potential low flow of the Gidabo and Gelana rivers has the capacity to irrigate about 365 ha and 11 ha during the driest month water demand period of the crops.

Computation was also done using the 80 %, 90%, 95% exceedance flow. The respective area to be irrigated is estimated. The storage requirement is also computed which need to meet the crop water demand on the identified area. Table 3.2 provides these results.

The storage requirement under different flow reliability level to irrigate the full potential of the identified area is also estimated. See results section.

Table 3.2 Area irrigated with different percentage exceedence flow

River	Area irrigated(ha) with --- percent reliability level of flow			
	80%	90%	95%	100%
Gidabo	809	560	435.5	365
Gelana	1818	1125	996	11
Bilate	152	95	87	76
Hare	177	135.5	127	77
Kulifo	13	8	4.0	2.0
Sille	4.5	2.6	2.5	1.0

3.4 Suggested irrigation methods on identified areas

Selection of suitable method of irrigation for particular soil type and terrain feature is a key prerequisite for sustainable irrigation system. Detailed analyses of the ecological, economical, technical and social factors provide a reasonable solution for the selection of best fit irrigation technology to suit particular condition.

The available technology, slope of the terrain, people's socio economic status, etc are also among the limiting factors in selecting appropriate method of irrigation. The present study considers the terrain feature (slope, topography) and the soil characteristics as selection criteria to identify between surface and other methods of irrigation. Of course other limiting factors such as type of common crops grown, socio economic status are also investigated. Based on these criteria a low land area near the west and east banks of main river are under less than 10% slope classification characterized by sandy loam to clay loam soil type. In this area surface irrigation, which can be set with relatively low initial investment and available technology, is of paramount importance.

On the other hand, a lot of cultivable lands are observed at high land as well as at small portion in lower banks of the riverside. These areas can be irrigated only in case of slope adjustment or power supply to pump the water up hills.

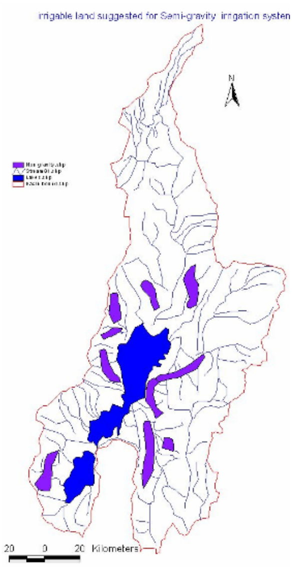

Figure 2.5 Potential irrigable land suggested for semi-gravity/ pumped System.

4 Results and Discussions

4.1 Soil data Results

Nitosols which are fertile and good for agricultural purposes is observed in alluvial fans and deltas of Lake Abaya and Chamo. It is also perceived in the immediate northern part of Lake Abaya and in the southern summit of Bilate basin. The lower Hare as well as Kulifo basins are also covered by patches of nitosols (soil number 24, 33,34, 38, 56). The southern tip of Gelana valley is characterized with fluvisols, still good for cultivation.

Luvisols with clay loam texture covers the southern tip of Lake Chamo. The Gelana valley is dominantly covered by cambic luvisols and lithosols of clay texture (soil 16, 40, 44, and 14). Cambic Vertisols, with effective depth greater than 150mm, clay to clay loam is observed in Alaba kulito area. These soil groups are problematic for cultivation, unless treatment is done.
Moderately suitable soils (vertisols & luvisols) exist in Gidabo and Gelana Valleys.

4.2 Land use Data Results:

The mapping units identified are reduced by comparing the soil classification. Much of the eastern and western escarpments of lakes area and great portion of the Gidabo and Gelana valleys are covered by rain fed peasant cultivation of grains (Land use 2.3). Irrigated agriculture is observed in Arba Minch and Mirab Abaya by medium scale estate farms (see land use 2.1). But small patches of lands under small scale irrigation are observed in other areas than already given in land use map. South western part of Bilate and north-eastern part of Gidabo basin are intensively cultivated areas (land use 2.2). Dense forest and open grass land with moderately cultivated land is observed in north- western Bilate escarpments. Dense woodlands with mixed agriculture in patches were seen in south-western Bilate area.

4.3 DEMs and Terrain feature

The upper areas of Hare river catchment (near Chencha), the south-west hills of lake Chamo (north-western parts of Bilate basin), eastern escarpments of Gidabo and Gelana high lands are characterized with rugged topography and elevation range of 2150m-3440m a.m.s. level. Typically the Chencha, northern Bilate basin and east of Lake Chamo have an elevation range of 2900m-3200m. The elevation difference caused a variation in slope within short distance interval.

On the contrary, significant parts of the alluvial funs of lake Abaya and Chamo (Arba Minch , Mirab Abaya, Wajifo , Sille) and the lower valleys of Gelana and Gidabo are characterized with elevation range below 1700. The smooth variation in elevation are suitable for surface irrigation with respect to topography.
The slope of the suggested low land areas is basically within suitable rage of slope classification for surface irrigation (less than 10 %). Detail description can be obtained from slope map derived from DEMs.

Slope of less than 10% is considered to be suitable for surface irrigation with minor adjustment to negotiate the natural slope. And slope ranges between 10-20 %, with suitable soil type and limited constraints found to be irrigated with pumped-gravity surface method. Irrigable lands with rugged topographic feature and with moderate slope range are considered to be irrigated by sprinkler and micro irrigation based on the specific soil type.

4.4 Crop water Requirement:

Crop water demand for common crops during the growing season is estimated using the available climatic, soil and cropping pattern data. The crop water demand over the entire identified potentially irrigable area is calculated and compared with the existing flow. Both the monthly low flow as well as the percent time of exceedance low flow is calculated and compared to the total water requirement of the crops over the irrigable area.

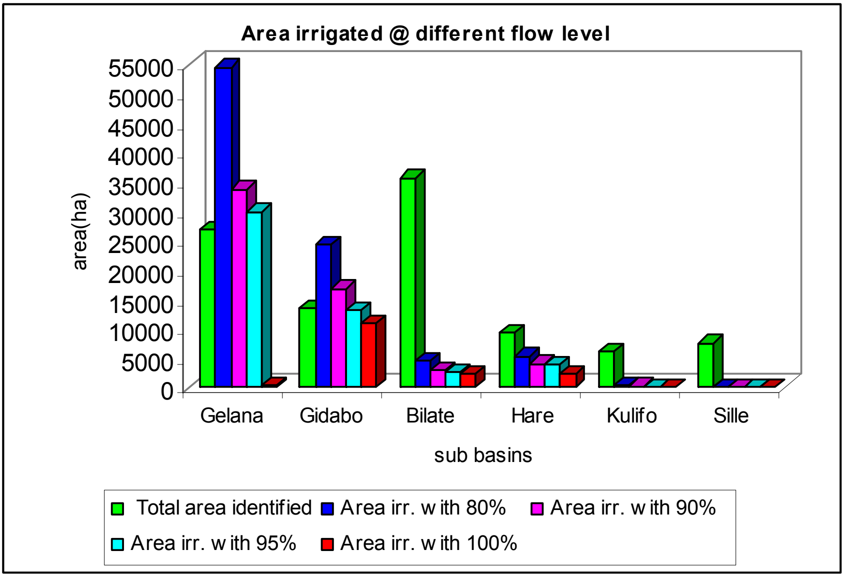

Figure 3.1 Area that can be irrigated at different flow levels

4.5 Storage requirement

Storage requirement to meet the demand of crop water requirement at critical month is estimated at different exccedence available flow level for each sub basin. It is observed that much storage is required in Bilate basin than others. This storage is not only due to the river water but can be provided in the form of small-scale water harvesting schemes.

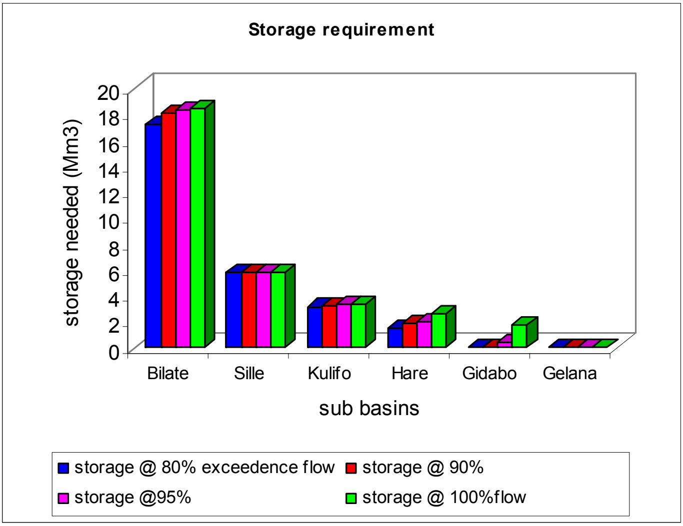

Figure 3.2 Storage requirements under different scenario of flow reliability

5 Summary and Conclusions

The irrigation suitability analysis described in the aforementioned sections basically tries to develop GIS based map of soil, land use, DEMs and stream net work of the basin. Furthermore it includes the drainage system and its potential capacity for their suitability for irrigation purpose. Superimposing are all these attributes implemented within the GIS environment for identifying potentially suitable areas for crop development and suggesting appropriate methods of irrigation. Nevertheless, compiling geo-referenced suitability data base (slope, soil, land use, water) for irrigation are among the main treatments undertaken during the study.

Large portion of Gelana and the lower delta of Hare, Kulifo and Bilate are characterized with suitable soil units. They are having good inherent fertility and high moisture holding capacity. Besides, these areas are with very flat land slope as observed from the DEMs which falls below 10 % and are suitable for surface irrigation.

In all the basins the potentially irrigable land exceeds the available surface water capacity during the low flow periods. This does not mean that the total annual flow capacity is less than the irrigation water demand. There is large amount of river flow as well as run off during the peak flow periods, which is able to satisfy the demand of irrigated area and even for some other energy generating options.

Due to seasonal variation of stream flow, provision of storage reservoirs have to be implemented in all basins. This is because the distribution of available water is not even both in space and time domain.

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