GRADIENT PROFILE ANALYSIS OF THE BLUE NILE (ABBAY) RIVER: A NATURAL RESOURCE DEVELOPMENT PERSPECTIVE

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Abstract: *A systematic gradient profile analysis of the Abbay River that forms the Ethiopian portion of the Blue Nile River is made to assess the potential of the river for irrigation and hydroelectric power development. The analysis was carried out by using Arc View GIS 3.2 software, digital elevation model (DEM), topographic maps, and factual field data. In this paper, the gradient of a river is used as a tool to identify potential sites for irrigation and hydroelectric power. The gradient value is computed from contours produced from the DEM by dividing the change in elevation between two successive 20 m contour intervals by the lateral distance. The contour values of the DEM have been crosschecked for accuracy against those produced by the Ethiopian Mapping Agency. The results indicate that there are three low gradient areas that are potential sites for irrigation development, and five high gradient areas that offer potential sites for hydroelectric power generation. This technique can be extended to explore potential sites for irrigation development and hydroelectric power generation for the tributaries and headwaters of the Abbay River System and other river systems.*

INTRODUCTION

Ethiopia is naturally endowed with great potential for water resource development but currently makes minimal use of these resources. The purpose of this investigation is to offer a step towards the exploration and sustainable utilization of these water resources by analyzing the gradient

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profile of the main trunk of the Abbay River within Ethiopia. The research provides a model to asses potential irrigation and hydroelectric power sites in a river system by using Arc View geographic information system and digital elevation models.

The Abbay River covers a total length of 928.5 km[1] and it drains about 199,812 km^2 of the highland plateau of Ethiopia and exposes rocks that vary in age and composition. As can be inferred from the geological map of Ethiopia (Mengesha et al, 1996), the main trunk of the Abbay River has exposed various rock types with the following percentages: 47.2 percent Precambrian age Basement complex (>545 Ma), 25.8 percent Paleozoic to Mesozoic age rocks (about 545-66.4 Ma), 21.9 percent Tertiary age volcanic and sedimentary rocks (66.4-1.6 Ma), and 5.1 percent Quaternary age sediments and volcanic rocks (1.6 Ma - present). The Precambrian complexes include the Alghe, Birbir, and the Tulu Dimtu metamorphic rock groups and the intrusive granitoid complexes. The Paleozoic to Mesozoic sedimentary rocks include the Adigrat, Abay, Urandab and Antalo, and Amba Aradom Formations. Similarly, the Tertiary volcanic rocks include the Ashangi and Makonnen basalts; and the Quaternary rocks include sediments and basalts.

The Abbay River has both ground and surface water sources (Shahin,1985). The majority of the groundwater comes from the Tana Basin, which is approximately 150,054 km^2 in areal extent (Ministry of Water Resources Abbay River Basin Integrated Development Master Plan Project, 1997), while the surface water comes from the Abbay River tributaries including the Beshilo, Weleka, Jamma, Guder, Anger, Dabas, Beles, Didessa and the rivers from the northwestern basins. The main trunk of the Abbay River drains through various soil types of different depths and varying chemical compositions. It traverses through shallow soils such as Leptosols (eutric and calcic), shallow to moderate depth soils such as Cambisols (eutric), and soils of high depth including Haplic nitosols and Fluvisols ((Ministry of

[1] This measurement is obtained from this particular research undertaking.

Water Resources Abbay River Basin Integrated Development Master Plan Project, 1997). The vegetative cover of the Abbay River Basin is dominantly open to dense woodland with a smaller extent of scrubland and grassland.

Previous research has provided very useful information on the geology of the Blue Nile River (Mengesha et al., 1990); the study, utilization, and management of the water of the Blue Nile River (Ethiopian Ministry of Water Resource, 1964; Waterbury, 1984; and Ministry of Water Resources Abbay River Basin Integrated Development Master Plan Project, 1997); hydro-politics of the Blue Nile River (Tesfaye, 2001); and history, legal, and developmental perspectives of the Blue Nile River (Gebre Tsadik, 2003). In spite of these earlier studies, broad scientific research which emphasizes on steps that are required to utilize the Abbay River is at its early stage.

The objective of this paper is to determine the gradient of the main trunk of the Abbay River System using Arc View GIS so as to identify potential sites for irrigation and hydroelectric power. The results offer a first step towards assessing potential sites for irrigation and hydroelectric power along the main trunk of the Abbay River. This research also provides information about the major types of parent material that are exposed by the Abbay River within the three potential irrigation development sites. The next phase of this research will be to extend this technique to the headwaters and tributaries of the entire Blue Nile Basin River system.

LOCATION OF THE STUDY AREA

The study area is located in northwest Ethiopia and includes the entire area of the Blue Nile Basin (Fig. 1). The study starts at the source of the Abbay River at its outlet at Lake Tana and ends at the Ethio-Sudan border.

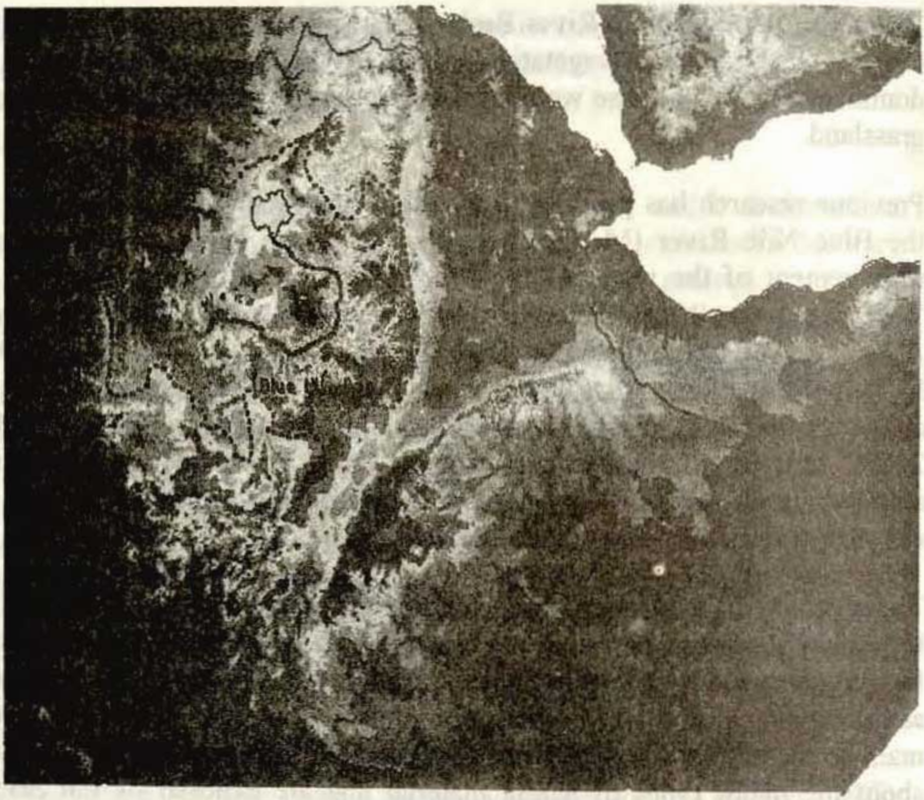

Figure1: Map of Ethiopia showing the location of the Abbay River (Abbay Wenz) and the Blue Nile Basin (stippled line) that are strictly within the geographic boundaries of Ethiopia.

MATERIALS AND METHODS

The following methods and materials are used to collect the relevant information required to identify the types of rocks that are exposed by the Abbay River, to conduct gradient analysis of the Abbay River, and to asses the sites for irrigation and hydroelectric power development. The geologic map of Ethiopia (Mengesha et al, 1996) at a scale of 1:2,000,000 that includes the Abbay Basin was scanned at 200 pixel/inch dpi setting and saved using Adobe Photoshop (version IV). This file was opened with

Adobe Illustrator Version-9 and the length of the river along with the areal extent of the various types of rocks that it has exposed was computed. GTOPO30 digital elevation model (DEM) of Ethiopia was downloaded from the United States Geological Survey (USGS) website (http://www.usgs.org) and the DEM data were unzipped and decompressed. The DEM file extension was replaced by "bil" and imported into Arc View GIS 3.2. The image was converted to a grid, and using the map calculator the 16 bit signed integer format of GTOPO30 format was changed to the ArcView-recognized DEM data in the ASCII format. Similarly, the value -9999 in GTOPO30 was used to mask ocean areas and this value was changed to null using map calculator. The grid data were projected to a Universal Transverse Mercator (UTM) Projection. To create a three-dimensional aspect of the GTOPO30 grid file, Avenue Script was used to first create a hill shed and then a rendered overhead perspective view. Contour values were calculated (Figure 2) and the gradient of the river was computed by dividing the change in elevation between two successive 20 meter contour intervals by the lateral distance between the two points.

The gradient value was computed for the entire Abbay River from its source at its outlet in Lake Tana to the Ethio-Sudan border using the following formula:

$$\text{Gradient} = (\Delta E)/D.$$

Where $\Delta E = |E2 - E1|$; E1 is elevation at site 1, E2 is elevation at site 2, and D is the lateral distance between sites E2 and E1 with a 20 m contour interval difference (Milne,1997; Whisman, 1998; and Yager, 2002). The elevation intervals and the computed gradient values are listed in Table I and a plot of these values is provided in Figure 3.

RESULTS

The gradient analysis of the main trunk of the Abbay River reveals that the total length of the river is 928.54 kms (Table I) and suggests that there are five potential sites, having gradient values between 0.02 to 0.05 for hydroelectric power generation (see Figs. 3 and 4: H1, H2, H3, H4 and H5) and three potential sites for irrigation development (see Figs. 3 and 4: I1, I2 and I3). Measurement of the lateral distance of each rock type exposed by the Abbay River was made starting at its source, the outlet at Lake Tana, and ending at the Ethio-Sudan border. The percentage of the areal coverage by each exposed rock unit along the traverse of the Abbay River is 47.2 percent Precambrian age Basement complex (>545 Ma), 25.8 percent Paleozoic to Mesozoic age rocks (about 545-66.4 Ma), 21.9 percent Tertiary age volcanic and sedimentary rocks (66.4-1.6 Ma), and 5.1 percent Quaternary age sediments and volcanic rocks (1.6 Ma - present) (Table II).

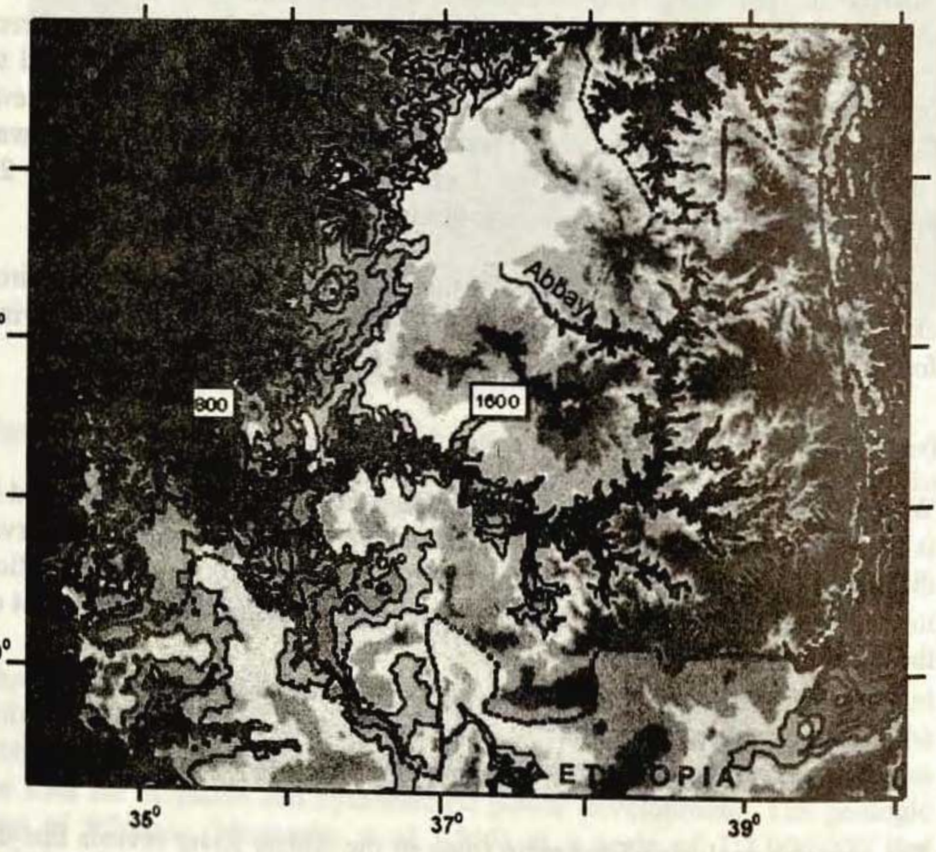

Figure 2: Topographic map of the Blue Nile Basin created from DEM using Arc View GIS software.

Table I: Elevation intervals, lateral distance (m) between sites with 20 m contour interval differences, and computed gradient values of the main trunk of the Abbay River. The measurements start at the source of the Abbay River, at its outlet at Lake Tana, and end at the Ethio-Sudan boarder.

No	Elevation interval (m)	Lateral distance (m)	Gradient value	No	Elevation interval (m)	Lateral distance (m)	Gradient value
1	1780-1760	4673.27	0.0043	34	1120-1100	43225.69	0.0005
2	1760-1740	3566.02	0.0056	35	1100-1080	9904.46	0.0020
3	1740-1720	2646.98	0.0076	36	1080-1060	23228.39	0.0009
4	1720-1700	2252.14	0.0089	37	1060-1040	3872.59	0.0052
5	1700-1680	2171.35	0.0092	38	1040-1020	30333.33	0.0007
6	1680-1660	6469.24	0.0031	39	1020-1000	13534.52	0.0015
7	1660-1640	6626.28	0.0030	40	1000-980	13434.25	0.0015
8	1640-1620	4828.49	0.0041	41	980-960	12411.41	0.0016
9	1620-1600	3370.68	0.0059	42	960-940	6018.64	0.0033
10	1600-1580	5066.05	0.0039	43	940-920	35589.24	0.0006
11	1580-1560	3757.33	0.0053	44	920-900	24428.16	0.0008
12	1560-1540	3810.74	0.0052	45	900-880	29491.08	0.0007
13	1540-1520	2146.63	0.0093	46	880-860	28309.35	0.0007
14	1520-1500	788.75	0.0254	47	860-840	23626.83	0.0008
15	1500-1480	10826.13	0.0018	48	840-820	21766.35	0.0009
16	1480-1460	9820.34	0.0020	49	820-800	24698.77	0.0008
17	1460-1440	2968.38	0.0067	50	800-780	19715.07	0.0010
18	1440-1420	1636.72	0.0122	51	780-760	5549.38	0.0036
19	1420-1400	1652.72	0.0121	52	760-740	3570.56	0.0056
20	1400-1380	2482.44	0.0081	53	740-720	595.97	0.0336
21	1380-1360	3181.03	0.0063	54	720-700	1289.21	0.0155
22	1360-1340	2100.13	0.0095	55	700-680	634.41	0.0315
23	1340-1320	675.2	0.0296	56	680-660	419.6	0.0477
24	1320-1300	1307.55	0.0153	57	660-640	392.24	0.0510
25	1300-1280	1293.77	0.0155	58	640-620	569.05	0.0351
26	1280-1260	8919.4	0.0022	59	620-600	4435.78	0.0045
27	1260-1240	429.63	0.0466	60	600-580	56289.24	0.0004
28	1240-1220	7566.58	0.0026	61	580-560	81197.28	0.0002
29	1220-1200	11637.64	0.0017	62	560-540	77561.24	0.0003
30	1200-1180	16589.84	0.0012	63	540-520	66230.31	0.0003
31	1180-1160	6544.68	0.0031	64	520-500	23444.46	0.0009
32	1160-1140	9932.99	0.0020	65	500-480	31976.94	0.0006
33	1140-1120	50183.74	0.0004	66	480-460	8874.9	0.0023

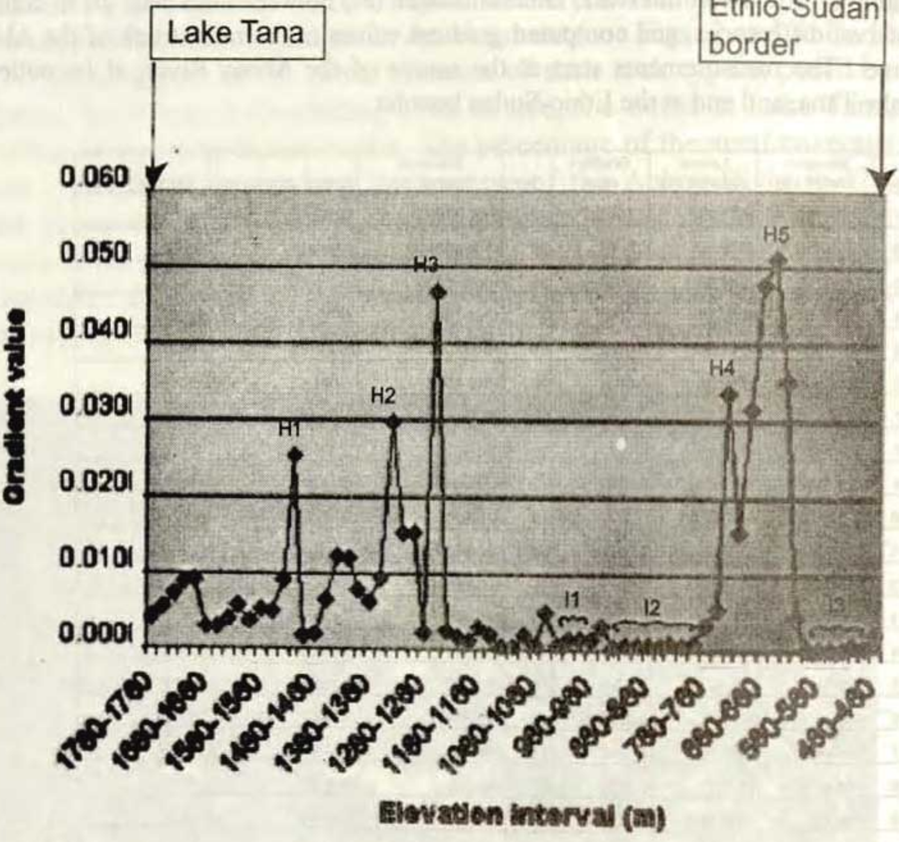

Figure 3: Gradient profile of the Abbay River from its source at its outlet at Lake Tana to the Ethio-Sudan border. Symbols: H1, H2, H3, H4 and H5 represent potential sites for hydroelectric power generation, and I1,I2 and I3 represent potential sites for irrigation development.

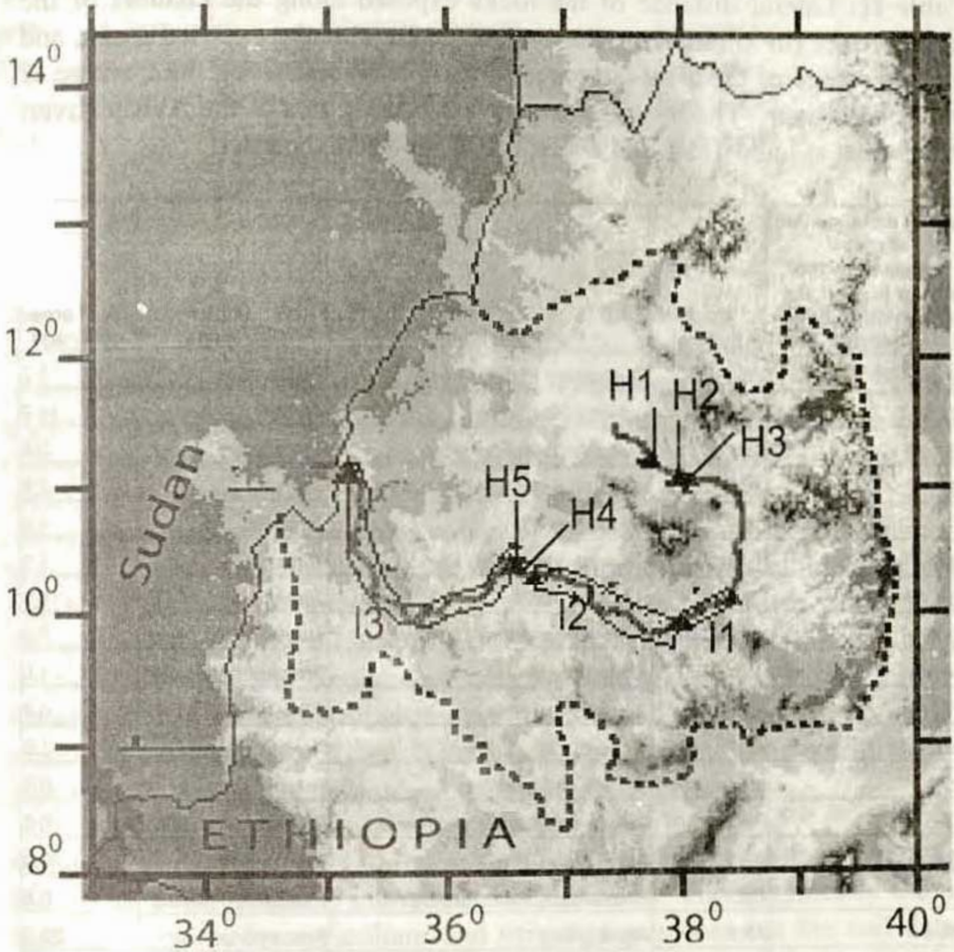

Figure 4: Location map of potential sites for hydroelectric power generation and irrigation development on the main trunk of the Abbay River system. Symbols as in Fig. 3. Stippled lines show the boundary of the Blue Nile Basin and dark line represents the Abbay River.

Table II: Lateral distance of the rocks exposed along the channel of the Abbay River (in kilometers), the symbol and age of the exposed rocks, and the percentage of the areal coverage by each rock unit along the traverse of the Abbay River. The measurements start at the source of the Abbay River, at its outlet at Lake Tana, and end at the Ethio-Sudan boarder.

Lateral distance (km) of rocks Exposed by the Abbay River (Lake Tana to Ethio-Sudan border)	Rock Symbol	Rock name	Rock age	% of area coverage
28.5	Qb1	Quaternary Plateau Basalt	Quaternary	3.2
124.2	P2a	Ashangi Formation	Tertiary	14.7
23.202	Ka	Amba Aradom Formation	Cretaceous	2.8
23.3	Jt	Urandab and Antalo Formation	Jurassic	2.8
8.9	Jb	Abay Formation	Jurassic	1.0
12.3	Jt	Urandab and Antalo Formation	Jurassic	1.5
36.4	Jb	Abay Formation	Jurassic	4.3
66.8	Ja	Adigrat Formation	Jurassic	7.9
8.4	AR1	Alghe group	Precambrian	1.0
3.7	Ja	Adigrat Formation	Jurassic	0.4
26.8	AR1	Alghe group	Precambrian	3.2
4.5	gt4	Granite and syenites	Precambrian	0.5
4.2	Pzt	Paleoz-earlyMesoz sediments	Paleozoic-Triassic	0.5
16.8	AR1	Alghe group	Precambrian	2.0
7.1	Pzt	Paleoz-earlyMesoz sediments	Paleozoic-Triassic	0.8
188.6	AR1	Alghe group	Precambrian	22.3
43.9	PR2td	Tulu Dimtu group	Paleozoic	5.2
5.8	AR1	Alghe group	Precambrian	0.7
12.4	PR2td	Tulu Dimtu group	Paleozoic	1.46
10.9	dt	Granitoid complexes	Precambrian	1.3
3.7	PR2b	Birbir Group	Paleozoic	0.4
4.9	PNmb	Makonnen Basalts	Neogene	0.6
4.7	Ja	Adigrat Formation	Jurassic	0.6
6.9	PNmb	Makonnen Basalts	Neogene	0.8
27.5	Ja	Adigrat Formation	Jurassic	3.3

8.9	PR2b	Birbir Group	Paleozoio	1.0
60.6	dt	Granitoid complexes	Precambrian	7.2
48.9	PNmb	Makonnen Basalts	Neogene	5.8
7.0	PR2b	Birbir Group	Paleozoic	0.8
14.8	Q	Quaternary sediments	Quaternary	1.8

DISCUSSION

There are several critical parameters that must be assessed when investigating potential sites for irrigation development and hydroelectric power generation. Some of these include: stream gradient, depicted in this paper; stream flow that provides hydrologic information needed to help define, use, and manage water resources; sustainability of the river and its groundwater reserve for a continuous and uninterrupted water supply; and soil types, soil depth and understanding of the large and extended area well beyond the borders of the Abbay River channel for a sustainable irrigation system. Of these parameters, gradient analysis that is described in this paper is a key variable. It provides detailed hydrometric data that can help in the search for and assessment of irrigation and hydroelectric power resources. This research technique can be extended to the headwaters and tributaries of the Abbay River System in order to assess their potential for hydroelectric power generation and irrigation development.

As shown in Figures 3 and 4, in the search for potential sites for irrigation, the flat areas are grouped into zones I1, I2, and I3. Topographically these areas are suitable for agriculture and irrigation purposes but the soil data indicates that zone I1 contains shallow soils and zone I2 lies within moderately deep soils. On the other hand, zone I3 contains soils with a maximum thickness and depth and has, therefore, the maximum potential for irrigation. A thorough feasibility study will require further analysis of the stream flow rates, detailed study of soil types and soil depths, the characteristics of the larger drainage area beyond the actual confines of the river channel, and sustainability of the river.

The hydroelectric power sites, H1, H2, H3, H4 and H5 that are indicated in Figures 3 and 4 are stretches of high gradient having a good potential for hydroelectric power development. Similarly, it is important to stress that further site analyses on market, location, topography, groundwater potential and sustainability of the river are required for a detailed assessment of hydroelectric power development along the main trunk of the Abbay River.

CONCLUSION AND RECOMENDATION

Digital elevation models, topographic maps, and Arc View GIS software together offer the tools for a detailed study of the gradient profile of the main trunk of the Abbay River. The results indicate that there are three zones with low gradient topography that are potential sites for irrigation: Zone I1 lies on shallow depth Leptosols (eutric, calcic), zone I2 on shallow to moderately depth Cambisols (eutric), and zone I3 on high depth Haplic nitosols and Fluvisols. Zone I3 has deep and fertile soils with mineral-rich source rocks and appears to offer the best potential area for irrigation. Additionally, five stretches of areas with high gradient have been identified as potential sites for hydroelectric power development. The results of this gradient analysis provide an important step in the detailed assessment of potential sites for irrigation and hydroelectric power development within the Abbay River. This method of gradient profile analysis is applicable for any river system and this approach will be extended to include the headwaters and tributaries of the Blue Nile Basin.

IMPLICATIONS

The outcome of this study is important towards exploration and efficient and sustainable utilization of the water resources of the Abbay River. This study will contribute to the transformation of subsistence agriculture and minimal utilization of hydroelectric power into large-scale commercial agriculture and maximized utilization of hydroelectric power. By so doing it will contribute to the eradication of the existing food insecurity, and electric power shortage of Ethiopia's growing population.

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