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Full Paper

Characterisation of sewage wastewater and assessment of downstream pollution along Huluka River of Ambo, Ethiopia

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Abstract: This study was conducted to assess the downstream pollution profiles of Huluka River due to sewage water contamination, and to provide the data on the physico-chemical properties and nutrient content of Huluka River in Ethiopia. The water quality indices, viz. temperature, pH, electrical conductivity, carbon dioxide content, total dissolved solids (TDS), hardness, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), calcium, magnesium, chloride, nitrate, sulphate, and phosphate were determined. Results reveal a worsening trend in the variations of most of these parameters from upstream to downstream areas of the river, which indicates an introduction of pollution load from domestic sewage and agricultural activities. For example, TDS and DO values for some downstream water samples do not conform to the accepted standards, and these samples also have eight to ten times higher values of BOD and COD compared to those for the upstream samples. Progressing downstream, the majority of the measured ions also show an increasing trend. All of these findings indicate that the quality of the water of Huluka River is declining.

Keywords: Huluka River, downstream pollution, Ambo, Ethiopia

Introduction

Ambo, one of the biggest developing towns in West Shoa zone of Ethiopia, is located 110 km from the western direction of Addis Ababa, the capital city. The town has three kebeles (villages) with a population of approximately 65,000. The place is endowed with one river, known as Huluka River, which separates the town into two major parts. Huluka River starts from Dendi Lake near the town of Wonchi, which is 39 km from Ambo, and flows from the southern pole of Ambo towards the northern direction of the town. The water content of the river varies from season to season with a mean daily water flow of about 15,000 and 75,000 m^3/day during dry and rainy season respectively [1]. In rural areas, the river water is used for drinking, sanitation, livestock, and agricultural purposes. However, sewage from residential areas near the river is directly expelled into the river and dense weeds have occupied the riverside, thus affecting the water flow.

Despite of its foul odour and toxicity caused by intensive exploitation by domestic and agricultural activities, the river is still used for various purposes including irrigation, recreation, and cattle washing. These observations may reveal the absence of policies protecting the water systems and/or of overt monitoring studies on Huluka River. At present limited or no reports dealing with the water quality of Huluka River have appeared in the literature. Hence, with the aims of assessing temporal variations and thereby encouraging public awareness of the water quality of the Huluka River, the present physico-chemical analysis study is conducted to evaluate the pollution caused by human influences along the river.

Materials and methods

Sampling location

To determine the pollution load from sewage wastewater, four representative samples were collected from domestic and municipal sources which discharge wastewater into Huluka River. The volume of the wastewater discharged into the river varies between 10,000 to 15,000 L/day [2]. The five sampling sites in the river are designated as S1 to S5 (Figure 1) as they reflect different activities along the watercourse of the river. Sampling site S1 represents the upper stream where the river enters into the town while S5 represents the lower stream of the river ending at Ambo. Sampling sites S2 to S4 are selected in between S1 and S5. The selected sampling sites are based on accessibility, safety, potential sources of pollution, and waste disposal activities. The sites are evenly distributed along the course of the river with more emphasis on polluted sites. The sampling sites span 10 km from upper to lower stream of the river.

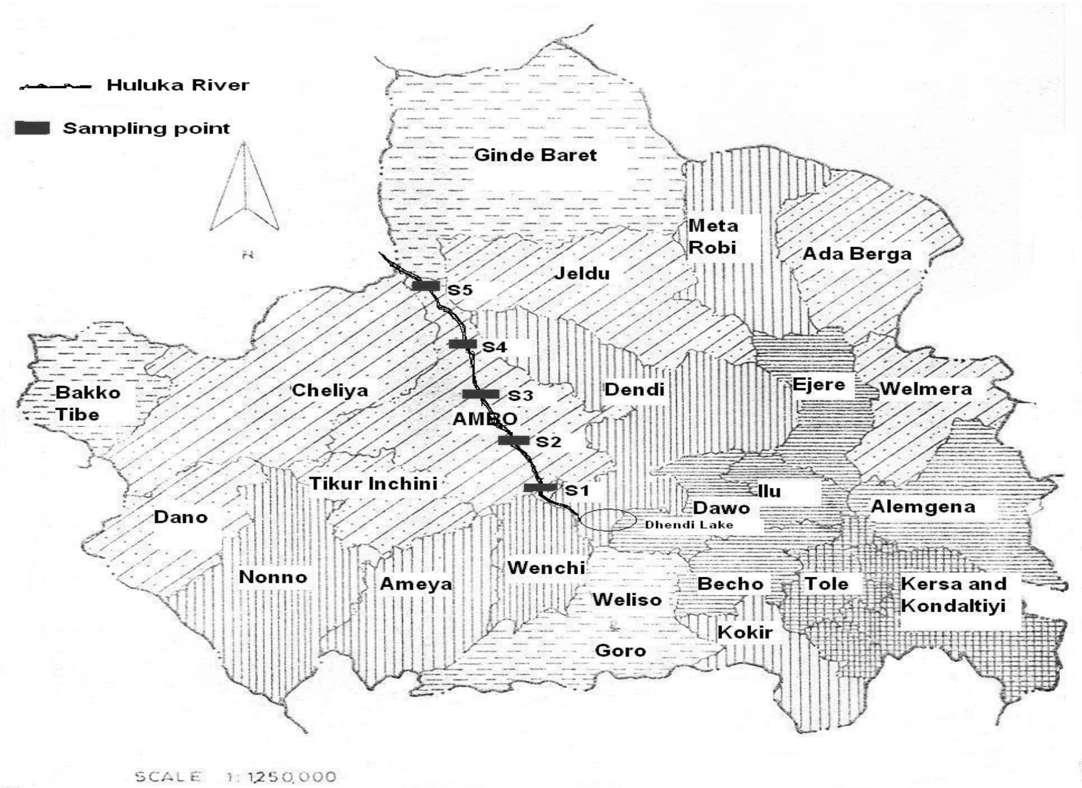

Figure 1. Map showing sampling points along Huluka River

Sampling procedures and methods of analysis

Samplings were carried out for a period of 6 months from February to July 2007, covering both dry and rainy seasons. Water samples (number of samples, n = 5) were collected in polyethylene cans at monthly intervals, and transported to the Department of Biology, Ambo College for further characterisation. The samples were analysed for temperature, pH, electrical conductivity (EC), carbon dioxide, TDS, hardness (as $CaCO_3$), DO, BOD, COD, calcium, magnesium, chloride, sulphate, nitrate, and phosphate, using standard methods for the examination of wastewater outlined in the APHA manual [3] and WHO/UNEP guidelines [4].

Results and Discussion

A detailed characterisation of sewage wastewater and downstream water samples has been carried out to determine the downstream pollution load in Huluka River. The composite raw sewage water in the town of Ambo which enters Huluka River at various points had the following characteristics: pH = 7.9, EC = 1420 µS/cm; total solids, DO, BOD, and COD = 850, 3.2, 250, and 540 mgL^{-1} respectively; nutrients: Ca, Mg, chloride, nitrate, phosphate and sulfate = 115, 95, 350, 9.28, 5.50, and 55 mgL^{-1} respectively. As for the Huluka River water samples, the results of analysis of the physico-chemical properties and the major ions and nutrients are summarised in Tables 1-2.

The temperature of the water samples range between 15.2-23.2^{o} C, which is noted to be above the maximum permissible limit (15^{o} C) of the Canadian Council of Ministers for Environment (CCME) guidelines for community water used as aesthetic object (Table 3), and is found to vary during the rainy and dry season. During the dry season (February to May), the temperature of Huluka River ranges between 22.4-23.2^o C while it is 15.2-17.8^o C during the rainy season. The pH of Huluka River is slightly alkaline in nature and ranges between a minimum of 7.40 in the rainy season and a maximum of 8.18 in the dry season (Table 1), which is the usual range of river waters [5]. The slight alkalinity could be due to the calcium bedrock weathering which reflects the importance of dissolution of limestone and dolomites in the watershed. This finding confirms the result of an earlier study on Tinishu Akaki River [6]. The pH is much lower at the entry point of the river to the town (S1) and increases to a maximum furthest downstream (S5). The increase could be due to the intermixing of the sewage wastewater whose pH value is greater than 8 at the downstream sampling points (S3-S5), thus indicating the possible presence of free ammonia, which is likely to pose problems when the water is to be used for drinking and fishing by the downstream users. Ammonia is much more toxic in alkaline water than in acidic one, being toxic to aquatic biota than when it is in the oxidised form [7]. However, all the values are still within the limit of CCME and WHO guidelines for livestock watering and irrigation water.

The electrical conductivity (EC) of water is a useful and convenient indicator of its salinity or total salt content, and the values for the water of Huluka River are between 168.6-597.1 µS/cm during the dry season and 125.4-541.2µS/cm during the rainy season. The lowest and highest EC values are within the recommended value of EC of potable water (750 µS/cm). Generally, the EC increases going downriver (S1 to S5) apparently due to the accumulation of domestic and sewage wastewater and also to the enrichment of electrolytes from mineralisation or weathering of sediment. This observation is supported by a similar study of Tinishu Akaki River [6], in which it was found that the water quality downstream was strongly degraded resulting in low dissolved oxygen and high conductivity. As for CO_2 content, there is also a marked increase going downstream in both seasons, varying between 3-20 mgL^{-1} and tends to be higher during the dry season (Table 1).

The value of total dissolved solids (TDS) is an important property used to evaluate the suitability of water for irrigation since the solids might clog both pores and components of the water distribution system. TDS is noted to be high during the dry season (109.6-388.1 mgL^{-1}) as compared to the rainy season (81.5-351.8 mgL^{-1}). Maximum values of TDS are obtained furthest downstream (S5) during both seasons. However, even the values for S4 water are larger than 283 mgL^{-1}, the mean value of TDS for the world's large rivers [6]. The increase in TDS can probably be related to pollution through discharge of domestic and sewage wastewater into the river. However, although some TDS values are higher than normal, it is found to be below the CCME guidelines for drinking water, i.e. 500 mgL^{-1} [8].

The increase in water hardness generally decreases metal toxicity, which is possibly due to Ca competition on the cell surface [9]. The total hardness of water samples from Huluka River is found to be within the maximum permissible limit according to the Environmental Protection Authority (EPA), i.e. 500 mgL^{-1} (Table 3). The total hardness as $CaCO_3$ varies from 12 (at S1) to 68 (at S5), which is classified as soft and moderately soft (Table 4) for all samples, based on hardness description used in the UK [10]. Although these values are within the acceptable ranges of the provisional discharge limits set by the EPA, the downstream samples are about three times harder compared to the upstream samples.

Table 1. Physico-chemical properties of water samples from Huluka River

Sample	**Temperature (^0C)**						**pH**						**Electrical conductivity (µS/cm)**					
	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul
S1	22.4	22.6	22.8	22.8	17.5	16.9	7.90	7.85	7.91	7.69	7.40	7.45	168.6	174.1	169.1	178.5	138.1	125.4
S2	22.4	22.6	23.1	22.8	17.5	16.8	7.97	7.97	7.95	7.89	7.41	7.45	171.2	172.2	175.2	165.9	148.3	145.9
S3	22.4	22.8	23.1	23.2	17.8	16.0	8.02	8.15	8.12	8.14	7.50	7.56	395.0	385.1	398.2	401.3	325.2	315.2
S4	22.6	22.4	23.2	23.1	16.0	16.2	8.10	8.05	8.04	8.05	7.71	7.71	553.6	561.2	578.2	545.5	498.2	481.5
S5	22.4	22.4	23.2	23.1	16.2	15.2	8.14	8.15	8.18	8.12	8.14	8.01	580.2	574.0	580.3	597.1	541.2	520.1
Sample	**CO_2 (mgL^{-1})**						**TDS (mgL^{-1})**						**Hardness ($mgL^{-1}CaCO_3$)**					
	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul
S1	5	5	6	6	3	3	109.6	113.2	109.9	116.0	89.8	81.5	20	21	21	20	15	12
S2	7	8	9	8	5	5	111.3	111.9	113.8	107.8	96.4	94.8	28	25	26	24	26	21
S3	8	8	13	10	8	7	256.8	250.3	258.8	260.9	211.4	204.9	60	59	58	50	58	58
S4	12	10	13	10	10	8	359.8	364.8	375.8	354.6	323.8	312.9	52	52	54	65	50	55
S5	20	15	15	13	18	12	377.1	373.1	377.2	388.1	351.8	338.1	68	67	65	54	58	60
Sample	**Temperature (^0C)**						**pH**						**Electrical conductivity (µS/cm)**					
	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul
S1	6.5	6.2	6.5	7.2	7.8	7.9	5.8	6.7	8.5	10.0	5.5	5.8	23	28	31	35	25	28
S2	5.0	5.0	5.1	5.4	6.8	6.9	7.0	7.6	8.0	11.0	6.1	5.9	94	102	105	95	90	95
S3	3.9	3.8	3.9	3.9	4.5	4.2	9.0	10.0	12.0	15.0	8.4	9.6	76	75	81	86	85	92
S4	3.5	3.5	3.2	3.1	4.1	4.0	25.0	31.0	22.0	23.0	21.0	18.0	150	165	157	184	168	152
S5	3.2	3.1	3.0	3.0	3.4	3.6	42.0	46.0	37.0	42.0	37.0	41.0	265	245	285	255	240	215

Table 2. Concentration of major ions and nutrients in water samples from Huluka River

Sample	**Ca (mgL^{-1})**						**Mg (mgL^{-1})**						**Cl (mgL^{-1})**					
	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul
S1	15	14	18	15	14	12	5.2	4.8	5.4	4.9	3.4	3.2	12.1	13.9	12.8	12.4	8.0	7.5
S2	28	25	29	28	22	20	13.9	14.0	13.2	12.7	8.1	8.9	20.8	20.2	21.0	22.3	15.2	15.4
S3	48	45	46	47	35	23	17.1	17.8	17.9	18.1	12.3	11.9	29.9	29.5	28.4	31.2	24.9	23.5
S4	55	58	59	60	35	34	18.3	19.1	21.0	17.6	13.1	12.1	38.6	35.6	35.1	38.2	31.9	28.7
S5	68	60	59	72	40	41	25.4	23.4	24.5	25.3	20.4	18.9	45.4	46.0	45.0	46.3	35.2	33.2
Sample	**Nitrate (mgL^{-1})**						**Phosphate (mgL^{-1})**						**Sulphate (mgL^{-1})**					
	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul
S1	0.88	0.76	0.89	0.91	1.12	1.35	0.12	0.15	0.12	0.15	0.20	0.30	16.2	15.2	15.8	15.5	16.5	18.5
S2	0.96	0.94	0.99	1.10	1.25	1.46	0.28	0.21	0.25	0.30	0.35	0.53	19.4	19.8	19.5	20.1	20.8	22.8
S3	1.07	1.23	1.35	1.25	1.32	1.57	0.62	0.65	0.67	0.81	0.65	0.80	22.6	22.6	23.0	23.2	25.3	25.9
S4	1.76	1.81	1.92	1.96	2.25	2.75	0.81	0.84	0.90	0.92	0.90	1.05	25.3	26.0	25.1	26.2	30.1	30.1
S5	2.64	2.60	2.81	2.89	3.15	3.58	1.20	1.20	1.28	1.45	1.40	1.60	28.9	29.5	29.0	21.1	32.3	33.4

As shown in Table 1, traversing downstream the value of dissolved oxygen (DO) steadily decreases with values ranging from 7.9-3.4 and 6.5-3.0 mgL^{-1} during the rainy and dry season respectively, which is an indicator that the quality of water increasingly worsens as it travels further downstream. Except for those at S1 and partly at S2, all other samples are found critically low in DO and do not conform to the value in the CCME guideline for the protection of aquatic life, i.e. 5.5-9.5 mgL^{-1}. The low DO level causes anaerobic conditions resulting in foul odour of the Huluka River. The lower levels of DO downstream may be attributed to the microbial utilisation of DO in the breakdown of organic compounds introduced by the discharge of domestic and sewage wastewater.

The pollution profile as indicated by BOD and COD is depicted graphically in Figure 2. They range from 5.5 to 46.0 mgL^{-1} and 23 to 285 mgL^{-1} respectively (Table 1). These values are within acceptable ranges (BOD $\leq$ 200 mgL^{-1}, COD $\leq$ 500 mgL^{-1}) according to the provisional discharge limits set by Ethiopian EPA [11]. However, the downstream samples (S4 and S5) are approximately eight times higher in BOD, and ten times higher in COD than the upstream samples and their BOD values exceed 15 mgL^{-1}, which is categorised as bad according to the UK general water quality assessment criteria (Table 4).

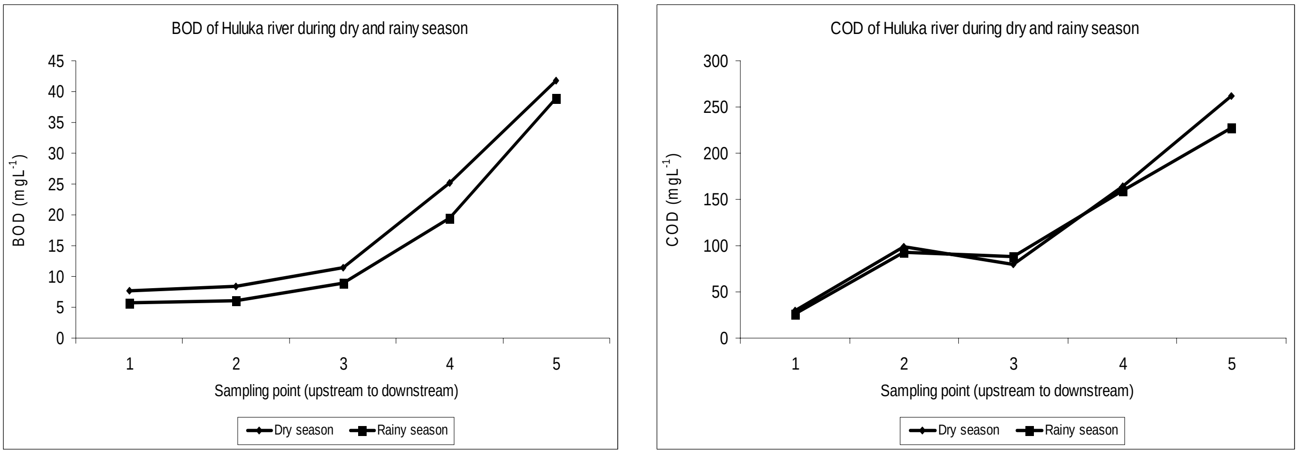

Figure 2. BOD and COD values of water samples from Huluka River

The measurement of Ca and Mg ion content of Huluka River registers 14-72 mgL^{-1} and 3.2-25.4 mgL^{-1} respectively (Table 2). As usual with most other indices, the Ca and Mg concentration increases progressively going downstream. However, the base cations are associated with the weathering of the bedrock and groundwater discharges. The extent of weathering in turn is associated with the reactivity of the rock and the surface area of contact between the rock and the river water [12].

The chloride ion concentrations in the river (7.5-35.2 mgL^{-1} during the rainy season and 12.1-46.3 mgL^{-1} during the dry season) are considered to be within the limit of the CCME for use as irrigation water and domestic purposes (Table 3). The probable sources of chloride could be the domestic and municipal sewage wastewater. The chloride concentration in downstream samples is up to four times that of the upstream ones and denotes the levels of pollution due to domestic and sewage wastewater intrusion.

Table 3. Water quality standards given by different organisations/bodies

Parameter	Desirable limit	Maximum permissible limit	Organisation/Body
Temperature (^{0}C)	-	15	CCME [8]
pH	7.0-8.5		WHO [13]
EC (μS/cm)	750	2500	WHO
DO (mgL^{-1})	5.5-9.5	-	CCME
TDS (mgL^{-1})	500	1500	ICMR [14]
Nitrate (mgL^{-1})	25	50	EC [15]
	-	45	WHO
Chloride (mgL^{-1})	100-700	1000	CCME
Phosphate (mgL^{-1})	0.35	6.1	EC
	1	-	WHO
Calcium (mgL^{-1})	1000 - Livestock	-	CCME
Total hardness (mgL^{-1})	100	500	EPA [16], ICMR
Sulphate (mgL^{-1})	<1000- Livestock	-	CCME

Note: CCME = Canadian Council of Minister for Environment; WHO = World Health Organization; ICMR = Indian Council of Medical Research; EC = European Community; EPA = Environmental Protection Agency

Table 4. The UK General Quality Assessment (GQA) for rivers and hardness description used in UK [6]

GQA grade	Description	BOD (mgL^{-1})	Hardness (mgL^{-1} $CaCO_3$)	Description
A	Very good	2.5	0-50	Soft
B	Good	4.0	50-100	Moderately soft
C	Fairly good	6	100-150	Slightly hard
D	Fair	8	150-200	Moderately hard
E	Poor	15	200-300	Hard
F	Bad	>15	>300	Very hard

The variation of the nitrate concentrations (0.76-3.58 mgL^{-1}) in the water of Huluka River follows the same trend described above. The recommended maximum concentration of nitrate for public water supplies which is 45 mgL^{-1} [13]. Although the values are still well within the maximum permissible limits (e.g. 25 mgL^{-1} for drinking water─Table 3), an elevated amount of nitrate pollution may cause blue baby syndrome [17]. On the other hand the phosphate concentrations (0.12-1.60 mgL^{-1}) although somewhat low upstream are above the desirable limits (0.35-1 mgL^{-1}) further downriver by European Community and WHO standards. The increase in nitrate and phosphate content is most probably a consequence of urban and/or agricultural activities, mainly from the use of fertilisers and phosphate-containing detergents [6].

The sulphate ion content in the river (15.2 to 33.4 mgL^{-1}) is well within the limit given by CCME for livestock use (<1000 mgL^{-1}). Sulphate ions are often the result of dissolution of gypsum, oxidation of sulfides, and atmospheric input [6].

Elevated concentrations of these ions are mostly attributed by domestic and municipal sewage water, whereby, proper measures should be administered before release into the receiving Huluka river. Though national standards for management of water quality in Ethiopia are in the process of enactment, the direct discharge of these pollutants to downstream of Huluka river could entail negative effects on the water quality river, as well as serious harm to the aquatic life and the downstream users.

Conclusions

As the water of Huluka River flows through Ambo, its quality is found to steadily deteriorate. All measured values for parameters relating to the water quality (except temperature) are found to have a worsening trend as one goes further downstream. Particularly, the levels of TDS, DO, BOD, and phosphate concentration determined for some of the downstream water samples are found to be outside the desirable ranges.

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