Water Supply

Water Supply Vol 22 No 1, 89 doi: 10.2166/ws.2021.286

The applications of Canadian water quality index for ground and surface water quality assessments of Chilanchil Abay watershed: The case of Bahir Dar city waste disposal site

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ABSTRACT

Surface water and groundwater have been experiencing increasing risks of contamination in recent years because of the poor management of the immense amounts of waste created by different human activities. Inappropriate dump sites have served for many years as marginal disposal sites for a wide range of wastes, including solid waste, fresh sewage and hazardous waste, in developing nations such as Ethiopia. Physical, anthropogenic and organic procedures continuously interact to deteriorate the waste. One of the results of these practices is artificially contaminated leachate, which is potentially hazardous waste from disposal sites. If not managed appropriately, such a dumping site can contaminate groundwater (through leachates) and surface water (through contaminant transport by flooding and groundwater movement). Along these lines, this study focuses on the applications of water quality index in the ground and surface water quality caused by the waste disposal site of Bahir Dar city within the Chilanchil Abay during the study period. Water testing was performed on five samples of surface water and six samples of groundwater in each month from 30th March (dry season) to 20th August (wet season). More than 13 water quality parameters, for example, pH, TDS, electrical conductivity, turbidity, temperature, dissolved oxygen (DO), TH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), TC, NO_3^-, PO_4^{3-}, Cr, Mn, and Pb contents, were examined in both ground and surface water. It was discovered that water quality status of the Chilanchil Abay watershed ranges from 15.87 to 36.6 for surface water and 42 to 46.2 for groundwater suggesting poor and marginal status for drinking water purpose.

Key words: Chilanchil Abay watershed, groundwater, surface water, waste disposal site, water quality index

HIGHLIGHTS

- The study assesses and evaluates the groundwater quality of Chilanchil Abay watershed through the investigations of spatial and temporal variations of physico-chemical and bacteriological parameters.
- This manuscript also evaluates the concentrations of the nutrients (phosphate and nitrate) in each borehole as compared to the standard values for drinking and irrigations.

INTRODUCTION

Water is the most abundant resource on earth but only 3% is accessible for human activities while the remaining is present in ocean as a salt water (Love & Luchsinger 2014). It may be available in various forms and quantity but its use for various purposes is the subject of quality. Of all the environmental concerns that developing countries face, the lack of adequate and clean water remains the most serious problem (Markandya 2006). Once contaminated, groundwater may forever remain polluted without remedy or treatment. Diseases may spring up through water pollution, especially groundwater contamination, and rapidly spread beyond human expectation because of its flow (Afolayan *et al.* 2012). Wastes of different types, mostly solid wastes are the major input of dumpsites/landfills. With respect to the hydrological analysis of groundwater, it flows from areas of higher topography towards areas of lower topography, thereby bringing about the examination of the degradable material which form leachate and contaminate the groundwater of the study area. Properly managed, derelict voids can be reclaimed by a process of sanitary landfilling, ultimately bringing the land back into productive use and providing much of the needed waste disposal sites (Kola-Olusanya 2012).

An integral part of any environmental monitoring program is the reporting of results to both managers and the general public. This poses a particular problem in the case of water quality monitoring because of the complexity associated with analyzing a large number of measured variables (Saffran 2001). The data sets contain rich information about the characteristics of the water resources. The classification, modeling and interpretation of data are the most important steps in the assessment of water quality. The CCME WQI (Canadian Council of Ministers of the Environment Water Quality Index) is used to evaluate success and failures in management strategies for improving water quality. In general, the index incorporates data from multiple water quality parameters into a mathematical equation that rates the health of a water body with a single number. That number is placed on a relative scale to justify the water quality in categories ranging from poor to excellent. The water quality is characterized as excellent (95–100), good (80–94), fair (65–79), marginal (45–64) and poor (0–44) (REFF).

This number can be easily interpreted and understood by political decision makers, non-technical water managers and the general public as a whole. The CCME Water Quality Index provides a convenient means of summarizing complex water quality data and facilitating its communication to a general audience and, like any other tool, requires knowledge about principles and basic concepts of water and related issues (Nikbakht 2004). It is a well-known method of expressing water quality that offers a stable and reproducible unit of measure which responds to changes in the principal characteristics of water (Brown *et al.* 1972). The specific variables, objectives, and time period used in the index are not specified and indeed, could vary from region to region, depending on local conditions and issues (Environment 2002). It is recommended that, at a minimum, four variables sampled at least four times be used in the calculation of index values. However, a maximum number of variables or samples are not specified.

The selection of appropriate water quality variables for a particular region is necessary for the index to yield meaningful results. Clearly, choosing a small number of variables for which the objectives are not met will provide a different picture than if a large number of variables are considered, only some of which do not meet objectives. It is up to the professional judgment of the user to determine which and how many variables should be included in the CCME Water Quality Index to most adequately summarize water quality in a particular region. It is also expected that the variables and objectives chosen will provide relevant information about a particular site. The index can be used both for tracking changes at one site over time, and for comparisons among sites. Sites can be compared directly only if the same variables and objectives are used. However, if the variables and objectives that feed into the index vary across sites, comparing among sites can be complicated.

In these cases, it is best to compare sites only as to their ability to meet relevant objectives. The advantages of this approach are as follows: it is flexible with respect to the type and number of water quality variables to be tested, the period of application, and the type of water body (stream, river reach, lake, etc.) tested. These decisions are left to the user. Therefore, before the index is calculated, the water body, time period, variables, and appropriate objectives need to be defined. The body of water to which the index will apply can be defined by one station (e.g., a monitoring site on a particular river reach) or by a number of different stations (e.g., sites throughout a lake). Individual stations work well, but only if there are enough data available for them. The more stations that are combined, the more general the conclusions will be. The time period chosen will depend on the amount of data available and reporting requirements of the user. Secondly, this model is flexible, allowing one to choose the parameters to use and standardize them according to the objectives and area of study. It is a useful tool for describing the state of the water column, sediments and aquatic life and for ranking the suitability of water for use by humans, aquatic life, wildlife, etc.

In developing nations, open and inappropriate dumping destinations have served as final removal sites for a wide range of wastes over many years; these wastes include city solid waste, raw sewage and hazardous wastes (Nathanson 2015). Physical, synthetic and natural procedures interact, resulting in breakdown of the waste. One of the side effects of these practices is artificially contaminated leachate, which is possibly unsafe waste from waste removal destinations. If legitimate waste administration is not performed, such dumping sites can contaminate groundwater (as a result of leachates) and surface water (through contaminant transport by flooding, wind and groundwater from open dump sites). The Bahir Dar city open landfill is one such open dump site and is situated in a location close to human settlements. The people who live close to the removal site (both downstream and upstream) utilize contaminated ground and surface water in their everyday activities. This poses a great deal of danger to those communities with respect to water quality. Along these lines, the focal point of this study was to survey and assess the water quality in that watershed, especially close to the waste disposal site, to assess its impact on ground and surface water quality.

METHODS

Descriptions of the study area

The Eriamecharia municipal waste disposal site is 5 km from Bahir Dar city, Ethiopia near the expressway to Addis Ababa and the Tis Abay waterfall. It is a part of the region in the Sebatamit provincial network. According to the Central Statistics Agency of Ethiopia (CSA 2007 G. C) approximately 6,401 people, 3,053 females and 3,348 males, live around the dump site. Its geographical location is as follows: latitude, 11.54; longitude, 37.38; height/length, 1,803 m at 3 degrees; and elevation above sea level, 1,801 m. The length and width of this irregularly shaped removal site are 384 m and 174 m, respectively. It was not equipped with liners or a leachate sorting system until ten years ago. This site was not efficiently planned before being utilized for waste removal/dumping. In addition, no environmental impact assessment was performed before this location was established as a waste disposal site. Trucks and other vehicles from various parts of the city gather the waste, carry it to this site and dump it in a disorganized manner. The waste is dumped as-is without isolation. The base amount of solid waste that is generated from the city and dumped at the site is private waste 12,610 kg/day, business waste 4,202 kg/day, service provider waste 98 kg/day, municipal waste 1,044 kg/day, and overall 22,774 kg/day (Source: Solid Waste Portrayal and Evaluation from the Bahir Dar city report, 2007). Currently, the average amount of waste dumped at the site is to be estimated 31,321 kg/day.

Sample collection, preservation and laboratory analyses

Water samples were gathered from the selected test areas close to the dump site, which is locally called Abohoy Manekia and Tikkurit. The samples were taken to the research centre for the investigation. The 11 testing sites were selected based on their availability and vicinity to contamination sources, for example, an accessible site, and lodging. A Worldwide Positioning System device (GPS etrex VISTA HCX) was utilized to identify the actual locations of the study sites, and the sites were geo referenced to guarantee consistency in the testing sites during the subsequent test periods. The test sites were deliberately chosen to incorporate the upstream and downstream networks, as shown in Figure 1. Sampling began during the dry season starting in March and proceeded through the wet season in August from all 11 study sites downstream and upstream of the dump site. The

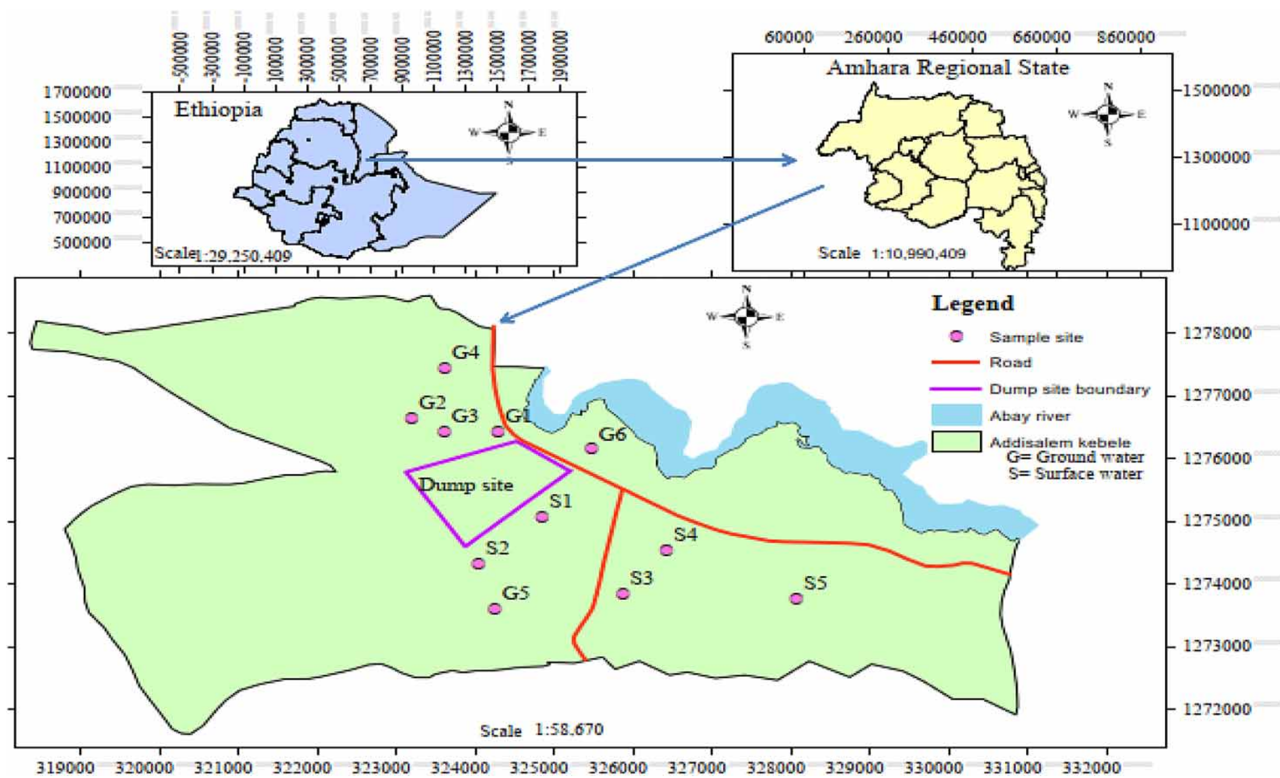

Figure 1 | Topographic map of the study area.

classifications of the wet and dry season in this paper was based on the Ethiopian calendar (September up to May was considered as dry season and June up to August was considered as wet season). Groundwater samples were taken from depths of 5–12 m (both upstream and downstream) using borer drills to obtain a 3 L maximum sample with a straightforward core approach that allowed the study of water at different borehole depths for groundwater samples (Hamad 2018). To evaluate the water quality, the water samples were kept in 1 L polyethylene plastic containers cleaned with a cleanser that did not contain metals, flushed with deionized water, treated with analytical grade nitric acid (HNO_3) for 24 h, and finally washed with ultrapure water. All water samples were stored in a cooler and brought to the lab at approximately the same time. All samples were kept at a consistent temperature of 4 °C to prevent the samples from deteriorating because of the impacts of light and temperature until the analysis was performed at the research centre (Clesceri *et al*. 1998). NaOH used for biochemical oxygen demand (BOD) analysis, ferroin was used as indicator, standardized 0.1M ferrous ammonium sulfate (FAS) was used as titrant and $K_2Cr_2O_7$ used as digestion solution during chemical oxygen demand (COD) analysis.The heavy metal (Cr, Pb, and Mn), phosphate (PO_4^{3-}) and nitrate (NO_3^-) contents were determined using a Palintest spectrophotometer (WAGTECH 8000).

Multi parameter water quality checker (model: YSI pro 30) was used to measure water quality for different parameters like temperature and total dissolved solids (TDS). Palintest spectrophotometer (model: WAGTECH 8000) was used to measure the concentrations of phosphates (PO_4^{3-}), nitrate (NO_3^-) and heavy metals (Cr and Mn) present in the water samples. Optical emission spectro photometer (model: OPTICAL 8000) was used to determine lead concentration. Digital portable pH meter (model: Banta 901, UK) was used to measure the pH of the water sample. Turbid meter (model: TN100) was used to measure the suspended and colloidal particles present in the water sample. Micropipette was used for taking exact volume of water sample, block digester (model: CR4200) was used for digestion of the sample solution, an ice box was used to avoid sample deterioration, incubator (model: YLD2001) was used to keep samples for 5 days during BOD analysis, and HI 98,193 dissolved oxygen meter was used to measure dissolved oxygen in a water sample. Generally all the procedures for the research facility analysis were performed according to the Standard Methods for the Examination of Water and Wastewater (Clesceri *et al.* 1998).

The type of water source and the depth of the sample sites affected the quality of the water samples since the migrations of leachates and availablity of dissolved oxygen are functions of the path of the depth. From Table 2, the river based surface water samples are a perennial source and this is also the reason why the sample sites were selected to be the target point. Water sampling was done at different points along the path of the flow.

Canadian council of Ministers of the Environment Water Quality Index (CCMEWQI) procedure

The index ranges from 0 to 100 and depending on the value; the water quality is characterized as excellent (95–100), very good (89–94), good (80–88), fair (65–79), marginal (45–64) and poor (0–44) (Khan *et al*. 2004). In general, scoring 80% and above met expectations for water quality and are of 'lowest concern' while sample points with scores below 40% did not meet expectations and are of 'highest concern' (Khan *et al.* 2004). These numbers are divided into five descriptive categories to simplify presentation. This index doesn't give any weighted numbers but treats the values of parameters in a mathematical way to ensure that all parameters contribute adequately in the final number of the index. The CCMEWQI model consists of three measures of variance from selected water quality objectives (scope; frequency; amplitude) (Khan *et al.* 2004). The 'Scope (F_1)' is the number of variables not meeting water quality objectives. The 'Frequency (F_2)' is the number of times these objectives are not met ('failed tests'). The 'Amplitude (F_3)' represents the amount by which failed tests do not meet their objectives. These three factors combine to produce a value between 0 and 100 that represents the overall water quality. The formulation of the WQI as described in the Canadian Water Quality Index 2001 technical report is as follows. (F_1), (F_2) and (F_3) are unit-less, they simply express numbers achieved as standard values (objectives), failings and the values which will deviate from the objective.

The measure for scope F_1 is calculated as follows:

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)*100 \tag{1}$$

The measure for frequency F_2 is calculated as follows:

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)*100 \tag{2}$$

The measure for amplitude, F_3 is calculated as follows:

Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective. When the test value does not exceed the objective:

$$\text{Excursion}_i = 100 - \left[\frac{objective}{\text{failed test values}}\right] - 1 \tag{3}$$

For cases in which the test value exceeds the objective:

$$\text{Excursion}_i = 100 - \left[\frac{\text{failed test value}}{\text{objective}}\right] - 1 \tag{4}$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (nse) is calculated as:

$$nse = \sum_{i=1}^{\infty} \frac{[Excursions]}{number\ of\ tests} \tag{5}$$

F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = \left(\frac{nse}{0.01_{nse} + 0.01}\right) \tag{6}$$

The water quality index (CCMEWQI) is then calculated as:

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{F_1^2 + F_1^2 + F_3^2}}{1.732}\right] \tag{7}$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the 'worst' water quality and 100 represents the 'best' water quality.

RESULTS AND DISCUSSIONS

Water quality index (CCMEWQI) for assessing changes in ground and surface water quality of Chilanchil Abay watershed

Calculation of Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) in the surface water quality of Chilanchil Abay watershed

Selections of parameters for testing of water solely depends upon for what purpose we going to use that water and to what extent we need its quality and purity. Water does contain different types of floating, dissolved and suspended things. Some physical test (turbidity, TDS, conductivity and temperature) should be performed for testing of its physical appearance while a chemical test should be performed for its BOD, COD, pH, TH, DO, nitrate, phosphate, manganese, lead and chromium and other characteristics to understand its deviation from the accepted limits. Based on this concept, the tested parameters listed below were selected upon the existing activities in the study area. For example, testing of phosphate and COD was due to the existence of shampoos and other chemical detergents on the dump site (derived from the city), nitrates due to fertilizers around the sample site (derived from the agricultural field), BOD and DO due to organic wastes, heavy metals due to dead batteries, discarded materials of garages, paints and leachates of the dump site and temperature, turbidity and TDS due to the physical phenomena of the sample site. As one can see from all tables below (Tables 1–15) there are 14 tested parameters, sample collection months and objectives. According to the existing circumstances of the study area, the researcher believes strongly those 14 parameters can show the conditions of a single

Table 1 | CCMEWQI index categorization scheme (Khan *et al*. 2004)

Rank	CCMEWQI-value	Description
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment conditions very close to natural or pristine levels
Very Good	89–94	Water quality is protected with a slight presence of threat or impairment conditions close to natural or pristine levels
Good	80–88	Water quality is protected with only a minor degree of threat or impairment, conditions rarely depart from natural or desirable levels
Fair	65–79	Water quality is usually protected but occasionally threatened or impaired conditions, sometimes depart from natural or desirable levels
Marginal	45–64	Water quality is frequently threatened or impaired, conditions often depart from natural or desirable levels
Poor	0–44	Water quality is almost always threatened or impaired, conditions usually depart from natural or desirable levels

Table 2 | Types of water source and distance of sampling point from the dump site

Sample number	Type of water source	Depth (m)	Distance from dump site
1	Shallow well	8	87 m from dumping site
2	Shallow well	5	187 m from dump site
3	Shallow well	10	229 m from dump site
4	Shallow well	11	501 m from dumping site
5	Spring		927 from dump site
6	Shallow	12	908 m from dump site
7	Surface (river source)	–	317 m from dumping site
8	Surface (river source)	–	115 m from dumping site
9	Surface (river source)	–	3 km from dumping site
10	Surface (river source)	–	3 km from dumping site
11	Surface (river source)	–	6 km from dumping site

water sample site. When samples are collected from the given sample place, the nature of the surroundings, river flow, weather conditions, general water condition and sampling frequency will affect the water quality of the sampling sites. Then, during this work, keeping all those phenomena was mandatory and that was why three months of dry season (March, April and May) and three months of wet season (June, July and August) were selected in order to observe its continual effect without a gap of the month from the beginning up to the end of sample taking since the study period was staying for 6 months. During sampling time, someone can take the sample weekly or monthly according to the changes that can occur. So this study considered monthly (30th end date of the month) after weekly preliminary observation. But the last month ended at 20th August, due to the high amount of rain from the mid-July up to mid-August during the study period so the researcher assured there is no significant change between 20th August and 30th August. The values of the objective table below indicates the standard values of drinkable water that all samples must be in range to be used for the planned target.

Calculation of CCMEWQI for sampling site one (SS_1)

$$F_1 = 6/14*100 = 42.86$$

$$F_2 = 25/84*100 = 29.76$$

Table 3 | Nutrient, heavy metal and physico-chemical characteristics of sampling site one (river source)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	12.11 ± 1.48	14.2 ± 0.66	15.14 ± 1.32	13.27 ± 1.29	15.1 ± 0.81	16.25 ± 0.54
TDS (mg/L)	500–1,000	1,254.5* ± 47.73	1,187* ± 38.96	1,242.1* ± 394.49	1,800* ± 253.14	1,442* ± 57.98	1,524* ± 58.69
Conductivity (μS/cm)	1,000	1,920* ± 35.36	1,870* ± 26.16	1,907* ± 94.05	2,040* ± 113.14	2,200* ± 96.87	2,337* ± 43.13
Temperature (°C)	12–25	25.6* ± 0.92	26.9* ± 0.21	27.2* ± 2.12	24.2 ± 0.78	23.1 ±	22.8 ±
pH	6.5–8.5	6.82 ± 0.06	6.91 ± 0.35	6.41 ± 1.11	7.98 ± 0.42	8.58* ± 0.33	8.11 ± 0.06
TH (mg/L)	500a	260 ± 6.36	251 ± 12.02	234 ± 25.46	270 ± 2.83	274 ± 9.89	288 ± 6.36
DO (mg/L)	5	2.05 ± 0.04	2.11 ± 0.02	2.14 ± 0.33	2.6 ± 0.15	2.81 ± 0.08	2.93 ± 0.04
BOD_5 (mg/L)	20	3.87 ± 0.11	3.72 ± 0.03	3.76 ± 0.04	3.81 ± 0.16	4.03 ± 0.39	4.58 ± 0.33
COD (mg/L)	150	74.8 ± 1.19	73.11 ± 1.77	70.6 ± 5.23	78 ± 4.24	84 ± 4.24	90 ± 2.83
Nitrate (mg/L)	10	0.05 ± 0.30	0.48 ± 0.07	0.38 ± 0.05	0.31 ± 0.08	0.42 ± 0.07	0.52 ± 0.04
Phosphate (mg/L)	0.1	0.18* ± 0.01	0.16* ± 0.03	0.12* ± 0.06	0.2* ± 0.04	0.25* ± 0.04	0.31* ± 0.03
Manganese (mg/L)	0.5	0.0065 ± 0.00007	0.0066 ± 0.004	0.00068 ± 0.012	0.018 ± 0.002	0.021 ± 0.006	0.029 ± 0.003
Lead (mg/L)	0.01	0.0019 ± 0.000071	0.0014 ± 0.00021	0.0017 ± 0.00007	0.0016 ± 0.012	0.018 ± 0.001	0.0025 ± 0.0003
Chromium (mg/L)	0.05	0.0067 ± 0.000071	0.0066 ± 0.000071	0.0065 ± 0.00034	0.055* ± 0.0042	0.061* ± 0.0078	0.072* ± 0.0014

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 06.
Total no of tests: 84. No of failed tests: 25.

Table 4 | Nutrient, heavy metal and physico-chemical characteristics of sampling site two (river source)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th Jun 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	9.803 ± 1.95	7.04 ± 1.34	8.94 ± 7.6	28.3* ± 0.31	27.86* ± 1.32	25.98* ± 0.021
TDS (mg/L)	500–1,000	1,275.8* ± 57.41	1,357* ± 157.96	1,133.6* ± 388.4	1,683* ± 190.92	1,413* ± 77.78	1,523* ± 13.42
Conductivity (μS/m)	1,000	1,936* ± 6.36	1,927* ± 9.19	1,914* ± 323.85	2,372* ± 118.7	2,540* ± 42.42	2,600* ± 36.77
Temperature (°C)	12–25	26.4* ± 0.71	27.4* ± 0.99	28.8* ± 2.83	24.8 ± 0.64	23.9 ± 0.57	23.1 ± 0.2,121
PH	6.5–8.5	7.59 ± 0.198	7.87 ± 0.177	7.62 ± 0.113	7.78 ± 0.45	8.42 ± 0.35	8.91* ± 0.799
TH (mg/L)	500	301 ± 16.26	324 ± 18.38	298 ± 22.63	330 ± 8.45	342 ± 11.31	358 ± 24.75
DO (mg/L)	5	1.81 ± 0.071	1.91 ± 0.021	1.94 ± 0.41	1.12 ± 0.19	1.39 ± 0.16	1.61 ± 0.13
BOD_5 (mg/L)	20	4.01 ± 0.085	4.13 ± 0.078	4.24 ± 0.198	4.52 ± 0.002	4.52 ± 0.26	4.89 ± 0.55
COD (mg/L)	150	87.2 ± 2.69	91 ± 3.96	85.4 ± 7.49	96 ± 2.12	93 ± 2.26	96.2 ± 1.27
Nitrate (mg/L)	10	0.0655 ± 0.00057	0.0647 ± 0.0030	0.069 ± 0.00524	0.81 ± 0.085	0.93 ± 0.0283	0.97 ± 0.035
Phosphate (mg/L)	0.1	0.13* ± 0.0141	0.15* ± 0.0283	0.11* ± 0.033	0.58* ± 0.0212	0.61* ± 0.0494	0.68* ± 0.0141
Manganese (mg/L)	0.5	0.0071 ± 0.0045	0.00069 ± 0.000017	0.00077 ± 0.000087	0.002 ± 0.00015	0.023 ± 0.0141	0.003 ± 0.000283
Lead (mg/L)	0.01	0.0024 ± 0.00042	0.0018 ± 0.0005	0.0025 ± 0.00014	0.0027 ± 0.00014	0.0029 ± 0.00021	0.003 ± 0.0021
Chromium (mg/L)	0.05	0.069* ± 0.00071	0.068* ± 0.0014	0.066* ± 0.0095	0.2* ± 0.021	0.23* ± 0.057	0.31* ± 0.014

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 07.
Total no of tests: 84. No of failed tests: 31.

Table 5 | Nutrients, heavy metals, biochemical and physico-chemical characteristics of sampling site three (river source)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	12.56 ± 0.59	13.4 ± 1.51	11.26 ± 3.09	15.64 ± 1.03	17.1 ± 1.20	18.8 ± 0.51
TDS (mg/L)	500–1,000	1,287* ± 60.1	1,202* ± 55.86	1,281* ± 423.56	682 ± 168.29	920 ± 55.15	842 ± 21.92
Conductivity (μS/cm)	1,000	1,971* ± 14.14	1,991* ± 7.78	1,980* ± 308.5	978 ± 9.19	991 ± 210.	1,289* ± 4.95
Temperature (°C)	12–25	25.9* ± 0.424	26.5* ± 0.35	26.01* ± 2.13	23 ± 0.64	22.1 ± 0.283	22.5 ± 1.061
PH	6.5–8.5	7.4 ± 0.42	7.35 ± 0.35	6.99 ± 2.13	8.96* ± 0.64	7.91 ± 0.283	9.03* ± 1.061
TH (mg/L)	500	257 ± 8	241 ± 16.5	274 ± 12.021	291 ± 6.364	300 ± 7.78	311 ± 24.75
DO (mg/L)	5	3.84 ± 0.120	4.01 ± 0.262	3.64 ± 2.306	9.73* ± 0.46	9.08* ± 0.035	9.13* ± 0.304
BOD_5 (mg/L)	20	3.96 ± 0.085	3.84 ± 0.14	3.64 ± 0.24	3.98 ± 0.13	3.79 ± 0.24	4.13 ± 0.12
COD (mg/L)	150	76 ± 1.41	74 ± 7.99	69.7 ± 7.99	81 ± 2.83	85 ± 5.16	92.3 ± 2.62
Nitrate (mg/L)	10	0.057 ± 0.0028	0.061 ± 0.00071	0.06 ± 0.417	0.65 ± 0.092	0.78 ± 0.057	0.86 ± 0.0354
Phosphate (mg/L)	0.1	0.21* ± 0.014	0.23* ± 0.021	0.2* ± 0.028	0.24* ± 0.014	0.26* ± 0.035	0.31* ± 0.021
Manganese (mg/L)	0.5	0.00064 ± 0.004	0.0065 ± 0.0042	0.00062 ± 0.00005	0.0014 ± 0.00012	0.018 ± 0.0011	0.0021 ± 0.00028
Lead (mg/L)	0.01	0.0021 ± 0.0004	0.0016 ± 0.0004	0.0022 ± 0.00014	0.0024 ± 0.00014	0.0026 ± 0.0003	0.003 ± 0.0004
Chromium (mg/L)	0.05	0.0062 ± 0.00004	0.06* ± 0.038	0.0061 ± 0.00024	0.04 ± 0.0001	0.039 ± 0.0014	0.041 ± 0.002

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 07.
Total no of tests: 84. No of failed tests: 22.

Table 6 | Nutrient, heavy metal, biochemical and physico-chemical characteristics of sampling site four (river source)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	5.21 ± 2.61	8.9 ± 1.16	7.26 ± 5.66	15.26 ± 0.53	16.01 ± 0.56	16.8 ± 0.63
TDS (mg/L)	500–1,000	1,332.5* ± 6.01	1,341* ± 6.86	1,350.7* ± 676.36	611.5 ± 185.62	874 ± 26.16	911 ± 21.92
Conductivity (μS/cm)	1,000	2,050* ± 27.56	2,089* ± 33.23	2,042* ± 807.52	900 ± 21.21	930 ± 198.697	1,211* ± 31.82
Temperature (°C)	12–25	25.7* ± 0.78	26.8* ± 0.57	27.6* ± 2.26	24.4 ± 0.42	23.8 ± 0.64	22.9 ± 0.92
PH	6.5–8.5	7.48 ± 0.085	7.36 ± 0.065	7.27 ± 1.64	9.59* ± 1.065	8.08 ± 0.983	9.47* ± 0.25
TH (mg/L)	500	268 ± 11.31	284 ± 4.95	277 ± 10.61	262 ± 6.36	271 ± 7.000	280.9 ± 7.42
DO (mg/L)	5	3.08 ± 0.11	3.24 ± 0.14	2.98 ± 3.53	7.97* ± 0.262	8.34* ± 0.438	8.96* ± 0.601
BOD_5 (mg/L)	20	3.41 ± 0.021	3.38 ± 0.0283	3.34 ± 0.191	3.61 ± 0.253	3.97 ± 0.276	4.36 ± 0.1061
COD (mg/L)	150	78.9 ± 3.61	84 ± 8.415	72.1 ± 14.8	93 ± 2.83	89 ± 2.97	84.8 ± 2.55
Nitrate (mg/L)	10	0.115 ± 0.08	0.23 ± 0.071	0.33 ± 0.192	0.601 ± 0.0078	0.59 ± 0.0283	0.63 ± 0.057
Phosphate (mg/L)	0.1	0.215* ± 0.046	0.28* ± 0.029	0.239* ± 0.050	0.31* ± 0.042	0.37* ± 0.0283	0.41* ± 0.05
Manganese (mg/L)	0.5	0.00052 ± 0.000032	0.005 ± 0.00032	0.00053 ± 0.00003	0.001 ± 0.00085	0.013 ± 0.008	0.0019 ± 0.00014
Lead (mg/L)	0.01	0.0022 ± 0.0004	0.0017 ± 0.0004	0.0023 ± 0.000141	0.0025 ± 0.00021	0.0022 ± 0.0005	0.0029 ± 0.00014
Chromium (mg/L)	0.05	0.065* ± 0.003	0.061* ± 0.0021	0.064* ± 0.00132	0.25* ± 0.014	0.27* ± 0.057	0.35* ± 0.0283

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 07.
Total no of tests: 84. No of failed tests: 27.

Table 7 | Nutrient, heavy metal, biochemical and physico-chemical characteristics of sampling site five (river source)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	9.5 ± 0.42	8.91 ± 0.72	7.89 ± 5.58	25.08* ± 16.405	23.2 ± 1.2021	24.9 ± 0.78
TDS (mg/L)	500–1,000	1,423.5* ± 15.91	1,401* ± 11.24	1,416.9* ± 514.70	689 ± 149.91	901 ± 31.82	856 ± 16.971
Conductivity (μS/cm)	1,000	2,170* ± 28.28	2,210* ± 33.23	2,163* ± 843.6	970 ± 7.8	981 ± 93.34	1,113* ± 51.62
Temperature (°C)	12–25	25.7* ± 0.071	25.8* ± 1.273	27.6* ± 2.263	24.4 ± 0.424	23.8 ± 0.636	22.9 ± 1.273
PH	6.5–8.5	7.03 ± 0.163	7.26 ± 0.049	7.33 ± 1.039	8.8* ± 0.615	9.67* ± 1.195	7.98 ± 0.226
TH (mg/L)	500	259 ± 17.67	234 ± 9.899	248 ± 28.28	288 ± 3.54	293 ± 4.808	299.8 ± 16.83
DO (mg/L)	5	4.83 ± 0.064	4.92 ± 0.46	4.27 ± 3.79	9.63* ± 0.15	9.42* ± 0.262	9.79* ± 0.64
BOD_5 (mg/L)	20	2.1 ± 0.078	2.21 ± 0.042	2.27 ± 0.05	2.34 ± 0.25	2.69 ± 0.297	3.11 ± 0.212
COD (mg/L)	150	69 ± 1.84	71.6 ± 0.78	72.7 ± 4.45	79 ± 1.41	77 ± 4.031	82.7 ± 0.21
Nitrate (mg/L)	10	0.0497 ± 0.0008	0.0486 ± 0.0024	0.052 ± 0.02	0.278 ± 0.008	0.29 ± 0.064	0.38 ± 0.042
Phosphate (mg/L)	0.1	0.11* ± 0.021	0.14* ± 0.0071	0.13* ± 0.031	0.57* ± 0.021	0.54* ± 0.064	0.63* ± 0.0354
Manganese (mg/L)	0.5	0.00064 ± 0.0004	0.0063 ± 0.0004031	0.0006 ± 0.0002	0.003 ± 0.00021	0.033 ± 0.0021	0.0038 ± 0.00021
Lead (mg/L)	0.01	0.0018 ± 0.0004	0.0013 ± 0.00125	0.019 ± 0.0013	0.0013 ± 0.00014	0.0011 ± 0.00042	0.0017 ± 0.00014
Chromium (mg/L)	0.05	0.056* ± 0.0021	0.059* ± 0.005	0.052* ± 0.012	0.22* ± 0.014	0.24* ± 0.04	0.29* ± 0.021

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 08.
Total no of tests: 84. No of failed tests: 28.

Table 8 | Variation of WQI of Chilanchil Abay watershed with different sampling sites

Sampling sites	Level	Status
SS_1	36.6	Poor
SS_2	15.87	Very poor
SS_3	35.59	Poor
SS_4	34.37	Poor
SS_5	32.22	Poor

$$\text{Excursion}_i = 100 - \left[\frac{\text{failed test value}}{\text{objective}}\right] - 1$$

$$100 - \left[\frac{1254.5}{1000}\right] - 1 + 100 - \left[\frac{1187}{1000}\right] - 1 + 100 - \left[\frac{1242.1}{1000}\right] - 1 + 100 - \left[\frac{1800}{1000}\right] - 1 + 100 - \left[\frac{1442}{1000}\right] - 1 + 100 - \left[\frac{1524}{1000}\right] - 1 +$$
$$100 - \left[\frac{1920}{1000}\right] - 1 + 100 - \left[\frac{1870}{1000}\right] - 1 + 100 - \left[\frac{1907}{1000}\right] - 1 + 100 - \left[\frac{2040}{1000}\right] - 1 + 100 - \left[\frac{2200}{1000}\right] - 1 + 100 - \left[\frac{2337}{1000}\right] - 1 +$$
$$100 - \left[\frac{25.6}{25}\right] - 1 + 100 - \left[\frac{26.9}{25}\right] - 1 + 100 - \left[\frac{27.2}{25}\right] - 1 + 100 - \left[\frac{8.58}{8.5}\right] - 1 + 100 - \left[\frac{0.18}{0.1}\right] - 1 +$$
$$100 - \left[\frac{0.16}{0.1}\right] - 1 + 100 - \left[\frac{0.12}{0.1}\right] - 1 + 100 - \left[\frac{0.2}{0.1}\right] - 1 + 100 - \left[\frac{0.25}{0.1}\right] - 1 + 100 - \left[\frac{0.31}{0.1}\right] - 1 + 100 - \left[\frac{0.055}{0.05}\right] - 1 +$$
$$100 - \left[\frac{0.061}{0.05}\right] - 1 + 100 - \left[\frac{0.072}{0.05}\right] - 1 = 2434.1$$

Table 9 | Nutrient, heavy metal and physico-chemical characteristics of sampling site one (shallow well)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	7.35 ± 0.255	6.99 ± 0.71	5.99 ± 1.22	7.71 ± 0.22	8.02 ± 0.98	9.4 ± 0.21
TDS (mg/L)	500–1,500	1,365 ± 41.72	1,306 ± 38.18	1,360 ± 570.99	552.5 ± 29.34	594 ± 12.021	611 ± 9.899
Conductivity (μS/cm)	1,000	2,061* ± 44.55	1,998* ± 38.18	2,052* ± 881.76	805 ± 37.48	858 ± 4.24	864 ± 36.06
Temperature (°C)	35	26 ± 1.41	28 ± 0.71	29 ± 2.76	25.1 ± 1.13	23.5 ± 0.99	22.1 ± 0.566
PH	5.5–7.5	7.42 ± 0.44	6.8 ± 0.33	6.34 ± 0.24	6 ± 0.14	6.2 ± 0.74	7.24 ± 0.17
TH (mg/L)	500	180 ± 1.41	178 ± 7.07	188 ± 1.41	190 ± 4.24	196 ± 2.83	200 ± 17.68
DO (mg/L)	5	2.06 ± 0.113	2.22 ± 0.014	2.2 ± 5.0421	9.33* ± 0.085	9.21* ± 0.1556	8.99* ± 0.35
BOD_5 (mg/L)	5	2.12 ± 0.11	2.27 ± 0.03	2.31 ± 0.071	2.41 ± 0.34	2.89 ± 0.18	3.14 ± 0.13
COD (mg/L)	150	62 ± 2.83	58 ± 3.54	63 ± 2.83	67 ± 3.54	72 ± 4.24	78 ± 4.95
Nitrate (mg/L)	50	0.0714 ± 0.0005	0.0721 ± 0.002	0.0699 ± 0.003	0.482 ± 0.02	0.51 ± 0.057	0.59 ± 0.05
Phosphate (mg/L)	0.1	0.0058 ± 0.0002	0.0061 ± 0.0004	0.0056 ± 0.00023	0.0024 ± 0.00021	0.0027 ± 0.002	0.00031 ± 0.00001
Manganese (mg/L)	0.5	0.002 ± 0.00014	0.0022 ± 0.00071	0.0012 ± 0.00020	0.03 ± 0.00141	0.032 ± 0.0014	0.039 ± 0.0057
Lead (mg/L)	0.01	0.00012 ± 0.000007	0.00011 ± 0.000084	0.0013 ± 0.00082	0.00014 ± 0.00001	0.00016 ± 0.00012	0.0019 ± 0.000141
Chromium (mg/L)	0.05	0.0034 ± 0.00021	0.033 ± 0.0014	0.031 ± 0.0018	0.006 ± 0.00037	0.059* ± 0.0057	0.051* ± 0.00283

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 03.
Total no of tests: 84. No of failed tests: 08.

Table 10 | Nutrient, heavy metal, biochemical and physico-chemical characteristics of sampling site two (shallow well)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	7.18 ± 0.622	6.3 ± 0.81	7.45 ± 1.38	5.5 ± 1.78	8 ± 0.106	7.85 ± 0.506
TDS (mg/L)	500–1,500	1,287 ± 7.78	1,298 ± 19.799	1,270 ± 498.16	565.5 ± 25.81	602 ± 62.22	514 ± 15.56
Conductivity (μS/cm)	1,000	2,258* ± 36.77	2,310* ± 231.93	1,982* ± 842.87	790 ± 7.78	801 ± 15.56	823 ± 26.87
Temperature (°C)	35	25.7 ± 1.201	27.4 ± 0.78	26.3 ± 1.63	24 ± 0.071	23.9 ± 0.92	22.6 ± 1.13
PH	5.5–7.5	8.76* ± 0.042	8.82* ± 0.28	8.43* ± 0.89	7.18 ± 0.27	6.8 ± 0.573	5.99 ± 0.42
TH (mg/L)	500	225 ± 12.021	242 ± 7.78	231 ± 18.38	257 ± 2.12	260 ± 13.93	279.7 ± 11.102
DO (mg/L)	5	2.54 ± 0.049	2.61 ± 0.156	2.39 ± 1.67	9.02* ± 0.106	8.87* ± 0.113	9.03* ± 0.403
BOD_5 (mg/L)	5	2.76 ± 0.035	2.81 ± 0.021	2.84 ± 0.099	2.98 ± 0.035	3.03 ± 0.184	3.29 ± 0.21
COD (mg/L)	150	64 ± 2.83	60 ± 4.95	67 ± 4.24	73 ± 3.54	78 ± 2.33	81.3 ± 4.74
Nitrate (mg/L)	50	0.703 ± 0.0057	0.711 ± 0.023	0.746 ± 0.029	0.705 ± 0.074	0.601 ± 0.049	0.67 ± 0.064
Phosphate (mg/L)	0.1	0.0054 ± 0.00021	0.0057 ± 0.0037	0.00053 ± 0.00027	0.039 ± 0.0025	0.0043 ± 0.0032	0.049 ± 0.0057
Manganese (mg/L)	0.5	0.0024 ± 0.00071	0.0023 ± 0.0001	0.0025 ± 0.0002	0.031 ± 0.003	0.035 ± 0.005	0.042 ± 0.004
Lead (mg/L)	0.01	0.00013 ± 0.00007	0.00012 ± 0.00002	0.00015 ± 0.00007	0.00016 ± 0.000021	0.00019 ± 0.000028	0.00023 ± 0.000071
Chromium (mg/L)	0.05	0.0026 ± 0.00018	0.028 ± 0.0018	0.0029 ± 0.0012	0.005 ± 0.000212	0.0053 ± 0.00057	0.0061 ± 0.00014

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 03.
Total no of tests: 84. No of failed tests: 09.

$$nse = \sum_{i=1}^{\infty} \frac{excursions\ i}{number\ \ of\ tests} = \frac{2434.12}{84} = 28.98$$

$$F_3 = \left(\frac{28.98}{0.01 * 28.98 + 0.01}\right) = 96.66$$

Table 11 | Nutrient, heavy metal, biochemical and physico-chemical characteristics of sampling site three (shallow well)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	7.34 ± 0.283	7.74 ± 0.61	6.88 ± 1.4	8.85 ± 0.283	8.45 ± 0.764	9.53 ± 0.38
TDS (mg/L)	500–1,500	1,469 ± 48.08	1,401 ± 41.72	1,460 ± 538.81	698 ± 39.68	754 ± 37.48	701 ± 9.192
Conductivity (µS/cm)	1,000	1,966* ± 48.08	1,898* ± 39.598	1,954* ± 743.1,692	903 ± 52.34	829 ± 33.941	877 ± 24.749
Temperature (°C)	35	26.1 ± 0.78	27.2 ± 0.283	26.8 ± 2.05	23.9 ± 0.58	23.08 ± 0.27	22.7 ± 0.495
PH	5.5–7.5	8.93* ± 0.021	8.96* ± 0.014	8.98* ± 2.11	6 ± 0.283	6.4 ± 0.764	7.48 ± 0.339
TH (mg/L)	500	206 ± 3.54	211 ± 7.78	222 ± 4.24	228 ± 16.26	251 ± 8.84	263.5 ± 9.55
DO (mg/L)	5	2.47 ± 0.064	2.38 ± 0.141	2.18 ± 1.68	8.8* ± 1.57	6.58* ± 0.46	7.23* ± 0.16
BOD_5 (mg/L)	5	2.82 ± 0.014	2.84 ± 0.05	2.91 ± 0.071	3.01 ± 0.071	3.11 ± 0.297	3.53 ± 0.28
COD (mg/L)	150	60 ± 1.41	62 ± 2.83	58 ± 7.78	69 ± 4.95	76 ± 7.71	86.9 ± 2.19
Nitrate (mg/L)	50	0.724 ± 0.005	0.731 ± 0.018	0.756 ± 0.081	0.87 ± 0.078	0.98 ± 0.014	0.96 ± 0.035
Phosphate (mg/L)	0.1	0.0476 ± 0.002	0.051 ± 0.0032	0.0465 ± 0.027	0.009 ± 0.0014	0.011 ± 0.0067	0.0015 ± 0.00057
Manganese (mg/L)	0.5	0.0031 ± 0.0002	0.00036 ± 0.000021	0.0033 ± 0.0025	0.039 ± 0.0028	0.043 ± 0.0035	0.048 ± 0.005
Lead (mg/L)	0.01	0.00003 ± 0.00001	0.0002 ± 0.00009	0.00034 ± 0.00021	0.00004 ± 0.000022	0.00035 ± 0.0002	0.00038 ± 0.00004
Chromium (mg/L)	0.05	0.0021 ± 0.0002	0.024 ± 0.00071	0.023 ± 0.005	0.03 ± 0.0057	0.038 ± 0.0024	0.0047 ± 0.0004

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 03.
Total no of tests: 84. No of failed tests: 09.

Table 12 | Nutrient, heavy metal and physico-chemical characteristics of sampling site four (shallow well)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	7.41 ± 0.37	7.94 ± 0.14	8.14 ± 0.41	8.72 ± 0.21	9.02 ± 0.29	8.61 ± 0.36
TDS (mg/L)	500–1,500	1,449.5 ± 36.42	1,398 ± 26.9	1,436 ± 634.3	539 ± 73.54	643 ± 19.1	670 ± 21.21
Conductivity (µS/cm)	1,000	2,216* ± 49.5	2,146* ± 88.39	2,271* ± 1067.7	761 ± 18.4	787 ± 57.98	869 ± 14.85
Temperature (°C)	35	26.1 ± 0.78	27.2 ± 0.283	26.8 ± 2.051	23.9 ± 0.58	23.08 ± 0.27	22.7 ± 0.57
PH	5.5–7.5	7.6* ± 1.05	9.08* ± 0.141	9.28* ± 2.32	6 ± 0.40	6.57 ± 0.453	7.21 ± 0.33
TH (mg/L)	500	193 ± 5.66	201 ± 4.243	207 ± 2.83	211 ± 14.14	231 ± 16.193	253.9 ± 12.4
DO (mg/L)	5	2.02 ± 0.092	2.15 ± 0.113	1.99 ± 4.78	8.75* ± 1.22	7.02* ± 0.50	7.73* ± 0.12
BOD_5 (mg/L)	5	2.31 ± 0.021	2.28 ± 0.064	2.19 ± 0.199	2.47 ± 0.177	2.72 ± 0.177	2.97 ± 0.085
COD (mg/L)	150	66.2 ± 2.263	69.4 ± 0.42	68.8 ± 1.56	71 ± 4.24	77 ± 3.68	71.8 ± 5.02
Nitrate (mg/L)	50	0.0855 ± 0.0011	0.087 ± 0.0028	0.091 ± 0.003	0.515 ± 0.02	0.49 ± 0.028	0.53 ± 0.057
Phosphate (mg/L)	0.1	0.036 ± 0.004	0.042 ± 0.0021	0.039 ± 0.0042	0.045 ± 0.00424	0.051 ± 0.00042	0.057 ± 0.0071
Manganese (mg/L)	0.5	0.00037 ± 0.00001	0.00035 ± 0.003	0.0039 ± 0.0008	0.015 ± 0.0014	0.017 ± 0.0042	0.023 ± 0.0021
Lead (mg/L)	0.01	0.0001 ± 0.000071	0.0011 ± 0.00014	0.0013 ± 0.00091	0.000015 ± 0.000006	0.000024 ± 0.00001	0.00028 ± 0.00002
Chromium (mg/L)	0.05	0.031 ± 0.0042	0.037 ± 0.003	0.033 ± 0.0184	0.007 ± 0.00035	0.0065 ± 0.00078	0.0054 ± 0.00042

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 03. Total no of tests: 84. No of failed tests: 09.

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{42.86^2 + 29.76^2 + 96.66^2}}{1.732}\right] = 100 - 63.4 = 36.6$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site one as poor for *30th March 2011* to *20th August 2011*.

Table 13 | Nutrient, heavy metal, biochemical and physico-chemical characteristics of sampling site five (shallow well)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	7.38 ± 0.67	6.45 ± 0.898	7.72 ± 0.91	9 ± 0.283	9.4 ± 0.42	10 ± 0.651
TDS (mg/L)	500–1,500	1,477 ± 16.97	1,501 ± 10.61	1,486 ± 526.09	742 ± 98.29	881 ± 19.092	908 ± 12.73
Conductivity (μS/cm)	1,000	2,252* ± 32.53	2,298* ± 24.73	2,263* ± 1040.86	791 ± 14.14	811 ± 132.231	998 ± 33.94
Temperature (°C)	35	25.6 ± 0.212	25.9 ± 0.7	27.3 ± 2.121	24.3 ± 0.283	23.9 ± 0.64	23 ± 0.71
PH	5.5–7.5	9.16* ± 0.17	9.4* ± 0.21	9.11* ± 1.12	7.53* ± 0.11	7.69* ± 0.078	7.58* ± 0.33
TH (mg/L)	500	231 ± 8.49	243 ± 16.97	219 ± 31.31	263 ± 11.3	279 ± 5.87	287.3 ± 32.74
DO (mg/L)	5	1.54 ± 0.13	1.72 ± 0.163	1.49 ± 0.382	2.03 ± 0.672	2.98 ± 0.078	3.09 ± 0.184
BOD_5 (mg/L)	5	3.06 ± 0.0354	3.11 ± 0.057	3.19 ± 0.495	3.89 ± 0.0495	3.96 ± 0.05	3.89 ± 0.43
COD (mg/L)	150	70.4 ± 0.85	71.6 ± 0.92	72.9 ± 0.78	74 ± 4.243	80 ± 5.57	87.9 ± 3.253
Nitrate (mg/L)	50	0.0743 ± 0.00035	0.0738 ± 0.0023	0.0705 ± 0.198	0.35 ± 0.13	0.54 ± 0.085	0.66 ± 0.071
Phosphate (mg/L)	0.1	0.061 ± 0.0057	0.069 ± 0.0042	0.063 ± 0.0014	0.061 ± 0.0424	0.66* ± 0.416	0.072 ± 0.0064
Manganese (mg/L)	0.5	0.0049 ± 0.0031	0.00052 ± 0.00042	0.00046 ± 0.0002	0.003 ± 0.00057	0.0038 ± 0.0028	0.043 ± 0.003
Lead (mg/L)	0.01	0.00014 ± 0.00001	0.00012 ± 0.00003	0.00016 ± 0.000012	0.0018 ± 0.00071	0.0019 ± 0.0004	0.0024 ± 0.0005
Chromium (mg/L)	0.05	0.049 ± 0.0064	0.058* ± 0.00071	0.057* ± 0.0021	0.06* ± 0.0021	0.063* ± 0.0035	0.068* ± 0.005

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 04.
Total no of tests: 84. No of failed tests: 15.

Table 14 | Nutrient, heavy metal, biochemical and physico-chemical characteristics of sampling site six (shallow well)

Parameters	Objective	30th March 2011	30th April 2011	30th May 2011	30th June 2011	30th July 2011	20th August 2011
Turbidity (NTU)	5–25	7.5 ± 0.51	6.78 ± 0.81	7.92 ± 0.60	7.07 ± 0.85	8.27 ± 2.072	11.2 ± 0.64
TDS (mg/L)	500–1,500	1,482 ± 5.66	1,474 ± 43.841	1,412 ± 552.96	630 ± 118.794	798 ± 28.991	839 ± 19.799
Conductivity (μS/cm)	1,000	2,237* ± 28.28	2,197* ± 20.51	2,226* ± 972.3	851 ± 13.44	870 ± 80.61	984 ± 29.71
Temperature (°C)	35	26.3 ± 0.424	26.9 ± 0.085	27.02 ± 2.09	24.06 ± 0.42	23.47 ± 0.35	22.98 ± 0.01
PH	5.5–7.5	8.5* ± 0.375	9.03* ± 0.113	8.87* ± 1.054	7.38 ± 0.064	7.47 ± 0.247	7.12 ± 0.255
TH (mg/L)	500	255 ± 2.83	259 ± 9.1924	246 ± 2.121	249 ± 3.54	254 ± 8.91	266.6 ± 7.5
DO (mg/L)	5	2.79 ± 0.021	2.82 ± 0.11	2.67 ± 3.85	8.12* ± 0.530	7.37* ± 0.64	8.27* ± 0.43
BOD_5 (mg/L)	5	2.87 ± 0.05	2.94 ± 0.14	2.74 ± 0.085	2.86 ± 0.04	2.91 ± 0.262	3.28 ± 0.12
COD (mg/L)	150	72 ± 0.71	73 ± 2.12	70 ± 3.54	75 ± 5.66	83 ± 5.87	91.3 ± 3.9
Nitrate (mg/L)	50	0.0769 ± 0.0001	0.0771 ± 0.003	0.0734 ± 0.032	0.52 ± 0.0071	0.51 ± 0.071	0.61 ± 0.01
Phosphate (mg/L)	0.1	0.099 ± 0.0014	0.097 ± 0.00071	0.098 ± 0.030	0.055 ± 0.004	0.061 ± 0.0431	0.67* ± 0.04
Manganese (mg/L)	0.5	0.0006 ± 0.000021	0.00063 ± 0.0004	0.0062 ± 0.003	0.002 ± 0.0005	0.0027 ± 0.0004	0.0033 ± 0.0003
Lead (mg/L)	0.01	0.0012 ± 0.00071	0.0011 ± 0.0002	0.0014 ± 0.0001	0.0016 ± 0.0007	0.0017 ± 0.0003	0.0021 ± 0.0002
Chromium (mg/L)	0.05	0.0054 ± 0.0007	0.0055 ± 0.0002	0.0058 ± 0.0024	0.04 ± 0.004	0.046 ± 0.004	0.051* ± 0.0035

Numbers with '*' are failed tests.
Total number of variables: 14. Total number of failed variables: 05.
Total no of tests: 84. No of failed tests: 11.

Table 15 | Variation of WQI of Chilanchil Abay watershed with different sampling sites

Sampling sites	Level	Status
SS_1	46.2	Marginal
SS_2	45.53	Marginal
SS_3	45.52	Marginal
SS_4	45.53	Marginal
SS_5	42.	Poor
SS_6	42.2	Poor

Calculation of CCMEWQI for sampling site two (SS_2)

$$F_1 = \frac{7}{14}*100 = 50$$

$$F_2 = 31/84*100 = 36.9$$

$$\text{Excursion}_i = 100 - \left[\frac{\text{failed test value}}{\text{objective}}\right] - 1$$

$$100 - \left[\frac{1275.8}{1000}\right] - 1 + 100 - \left[\frac{1357}{1000}\right] - 1 + 100 - \left[\frac{1133.6}{1000}\right] - 1 + 100 - \left[\frac{1683}{1000}\right] - 1 + 100 - \left[\frac{1413}{1000}\right] - 1 +$$
$$100 - \left[\frac{1523}{1000}\right] - 1 + 100 - \left[\frac{1936}{1000}\right] - 1 + 100 - \left[\frac{1927}{1000}\right] - 1 + 100 - \left[\frac{1914}{1000}\right] - 1 + 100 - \left[\frac{2372}{1000}\right] - 1 +$$
$$100 - \left[\frac{2540}{1000}\right] - 1 + 100 - \left[\frac{2600}{1000}\right] - 1 + 100 - \left[\frac{26.4}{25}\right] - 1 + 100 - \left[\frac{27.4}{25}\right] - 1 + 100 - \left[\frac{28.8}{25}\right] - 1 +$$
$$100 - \left[\frac{8.91}{8.5}\right] - 1 + 100 - \left[\frac{0.13}{0.1}\right] - 1 + 100 - \left[\frac{0.15}{0.1}\right] - 1 + 100 - \left[\frac{0.11}{0.1}\right] - 1 + 100 - \left[\frac{0.58}{0.1}\right] - 1 +$$
$$100 - \left[\frac{0.61}{0.1}\right] - 1 + 100 - \left[\frac{0.68}{0.1}\right] - 1 + 100 - \left[\frac{0.069}{0.05}\right] - 1 + 100 - \left[\frac{0.068}{0.05}\right] - 1 + 100 - \left[\frac{0.066}{0.05}\right] - 1 +$$
$$100 - \left[\frac{0.2}{0.05}\right] - 1 + 100 - \left[\frac{0.23}{0.05}\right] - 1 + 100 - \left[\frac{0.31}{0.05}\right] - 1 + 100 - \left[\frac{28.3}{25}\right] - 1 +$$
$$100 - \left[\frac{27.86}{25}\right] - 1 + 100 - \left[\frac{25.98}{25}\right] - 1 = 2998.23$$

$$nse = \sum_{i=1}^{\infty} \frac{excursions\ i}{number\ of\ tests} = \frac{2998.23}{84} = 35.69$$

$$F_3 = \left(\frac{35.69}{0.01*35.69 + 0.01}\right) = 97.27$$

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{50^2 + 36.9^2 + 97.27^2}}{1.732}\right] = 100 - 84.13 = 15.87$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site two as very poor for *30th March 2011 to 20th August 2011*.

Calculation of CCMEWQI for sampling site three (SS_3)

$$F_1 = 7/14*100 = 50$$

$$F_2 = 22/84*100 = 26.2$$

Excursion$_i$ was calculated using equation (4)

$$100-\left[\frac{1287}{1000}\right]-1+100-\left[\frac{1202}{1000}\right]-1+100-\left[\frac{1281}{1000}\right]-1+100-\left[\frac{1971}{1000}\right]-1+$$
$$100-\left[\frac{1991}{1000}\right]-1+100-\left[\frac{1980}{1000}\right]-1+100-\left[\frac{1289}{1000}\right]-1+100-\left[\frac{25.9}{25}\right]-1+$$
$$100-\left[\frac{26.5}{25}\right]-1+100-\left[\frac{26.01}{25}\right]-1+100-\left[\frac{8.96}{8.5}\right]-1+100-\left[\frac{9.03}{8.5}\right]-1+$$
$$100-\left[\frac{9.73}{5}\right]-1+100-\left[\frac{9.08}{5}\right]-1+100-\left[\frac{9.13}{5}\right]-1+100-\left[\frac{0.21}{0.1}\right]-1+$$
$$100-\left[\frac{0.23}{0.1}\right]-1+100-\left[\frac{0.2}{0.1}\right]-1+100-\left[\frac{0.24}{0.1}\right]-1+100-\left[\frac{0.26}{0.1}\right]-1+$$
$$100-\left[\frac{0.31}{0.1}\right]-1+100-\left[\frac{0.06}{0.05}\right]-1=2140.46$$

nse was calculated using equation (5)

$$nse=\frac{2140.46}{84}=25.48$$
$$F_3=\left(\frac{25.48}{0.01*25.48+0.01}\right)=96.22$$
$$\text{CCMEWQI}=100-\left[\frac{\sqrt{50^2+26.2^2+96.22^2}}{1.732}\right]=100-64.41=35.59$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site three as poor for *30th March 2011* to *20th August 2011*.

Calculation of CCME WQI for sampling site four (SS_4)

$$F_1=7/14*100=50$$
$$F_2=27/84*100=32.143$$

$$\text{Excursion}_i=100-\left[\frac{1332.5}{1000}\right]-1+100-\left[\frac{1341}{1000}\right]-1+100-\left[\frac{1350.7}{1000}\right]-1+100-\left[\frac{2050}{1000}\right]-1+$$
$$100-\left[\frac{2089}{1000}\right]-1+100-\left[\frac{2042}{1000}\right]-1+100-\left[\frac{1211}{1000}\right]-1+100-\left[\frac{25.7}{25}\right]-1+100-\left[\frac{26.8}{25}\right]-1+$$
$$100-\left[\frac{27.6}{25}\right]-1+100-\left[\frac{9.59}{8.5}\right]-1+100-\left[\frac{9.47}{8.5}\right]-1+100-\left[\frac{7.97}{5}\right]-1+100-\left[\frac{8.34}{5}\right]-1+$$
$$100-\left[\frac{8.96}{5}\right]-1+100-\left[\frac{0.215}{0.1}\right]-1+100-\left[\frac{0.28}{0.1}\right]-1+100-\left[\frac{0.239}{0.1}\right]-1+100-\left[\frac{0.31}{0.1}\right]-1+$$
$$100-\left[\frac{0.37}{0.1}\right]-1+100-\left[\frac{0.41}{0.1}\right]-1+100-\left[\frac{0.065}{0.05}\right]-1+100-\left[\frac{0.061}{0.05}\right]-1+100-\left[\frac{0.064}{0.05}\right]-1+$$
$$100-\left[\frac{0.25}{0.05}\right]-1+100-\left[\frac{0.27}{0.05}\right]-1+100-\left[\frac{0.35}{0.05}\right]-1=2611.643$$

$$nse=\frac{2611.64}{84}=31.091$$
$$F_3=\left(\frac{31.091}{0.01*31.091+0.01}\right)=96.884$$
$$\text{CCMEWQI}=100-\left[\frac{\sqrt{50^2+32.143^2+96.884^2}}{1.732}\right]=100-65.63=34.37$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site four as poor for *30th March 2011* to *20th August 2011*.

The failed variables/tests to be higher or lower was due to the locations of the sample sites and seasonal changes.

Calculation of CCMEWQI for sampling site five (SS_5)

$$F_1 = 8/14*100 = 57.14$$

$$F_2 = 28/84*100 = 33.33$$

$$\text{Excursion}_i = 100 - \left[\frac{1423.5}{1000}\right] - 1 + 100 - \left[\frac{1401}{1000}\right] - 1 + 100 - \left[\frac{1416.9}{1000}\right] - 1 + 100 - \left[\frac{2170}{1000}\right] - 1 +$$

$$100 - \left[\frac{2210}{1000}\right] - 1 + 100 - \left[\frac{2163}{1000}\right] - 1 + 100 - \left[\frac{1113}{1000}\right] - 1 + 100 - \left[\frac{25.7}{25}\right] - 1 + 100 - \left[\frac{25.8}{25}\right] - 1 +$$

$$100 - \left[\frac{27.6}{25}\right] - 1 + 100 - \left[\frac{25.08}{25}\right] - 1 + 100 - \left[\frac{8.8}{8.5}\right] - 1 + 100 - \left[\frac{9.67}{8.5}\right] - 1 + 100 - \left[\frac{9.63}{5}\right] - 1 +$$

$$100 - \left[\frac{9.42}{5}\right] - 1 + 100 - \left[\frac{9.79}{5}\right] - 1 + 100 - \left[\frac{0.11}{0.1}\right] - 1 + 100 - \left[\frac{0.14}{0.1}\right] - 1 + 100 - \left[\frac{0.13}{0.1}\right] - 1 +$$

$$100 - \left[\frac{0.57}{0.1}\right] - 1 + 100 - \left[\frac{0.54}{0.1}\right] - 1 + 100 - \left[\frac{0.63}{0.1}\right] - 1 + 100 - \left[\frac{0.056}{0.05}\right] - 1 + 100 - \left[\frac{0.059}{0.05}\right] - 1 +$$

$$100 - \left[\frac{0.052}{0.05}\right] - 1 + 100 - \left[\frac{0.22}{0.05}\right] - 1 + 100 - \left[\frac{0.24}{0.05}\right] - 1 + 100 - \left[\frac{0.29}{0.05}\right] - 1 = 2708.45$$

$$nse = \frac{2708.45}{84} = 32.24$$

$$F_3 = \left(\frac{32.24}{0.01*32.24 + 0.01}\right) = 96.992$$

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{57.14^2 + 33.33^2 + 96.992^2}}{1.732}\right] = 100 - 67.78 = 32.22$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site five as poor for *30th March 2011* to *20th August 2011*.

In this study, the CCMEWQI was applied and tested for the Chilanchil Abay watershed using the method described by CCME 2001 guidelines (equations 1, 2, 6 and 7) and the results obtained from the application of this index with respect to nutrients, heavy metals and physico-chemical characteristics of surface water were presented in Table 8.

Analysis in Chilanchil Abay watershed Table 8 and Figure 2 shows the variation of WQI with CCME standard level to evaluate the status of existing water quality in the study area. The calculated results obtained from all sample points of surface water (Table 8) were showing poor status for 30th March 2011 to 20th August 2011. Considering CCMEWQI (Table 1) or considering all observation in each sampling site, WQI for Chilanchil Abay watershed is poor, which indicates that water quality of this sampling site is always endangered or deteriorated; conditions usually deviate from natural or desirable levels. Figure 2 shows considering all sample points, sample point two has shown the worst quality in context of CCME-WQI. The reasons may include direct discharge of effluent from the waste disposal site which lies within a few meters from the sampling site. However, value for WQI obtained from CCMEWQI calculation indicates that the water must be treated to remove the physical and chemical impurities since there is a significant effect from the open field waste disposal site. Generally, the CCMEWQI has shown that, the use of the Chilanchil Abay watershed for various domestic activities such as drinking, cooking, recreation and livestock are not recommended. This is because the status of the watershed has departed from desirable or permissible levels in most of its nutrients, heavy metals and physico-chemical parameters (Figures 2 and 3). It is evident from the results that water quality in the Chilanchil Abay watershed has degraded considerably due to human activities such as anarchy way of waste dumping (absence of engineered/sanitary way of landfill), open field defecation, contamination of water by household sewage, etc.

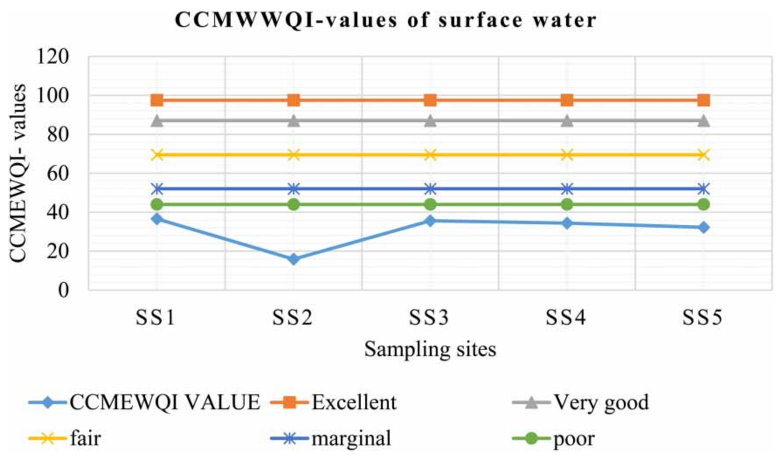

Figure 2 | Variations of WQI at different sampling sites of surface water in the study area.

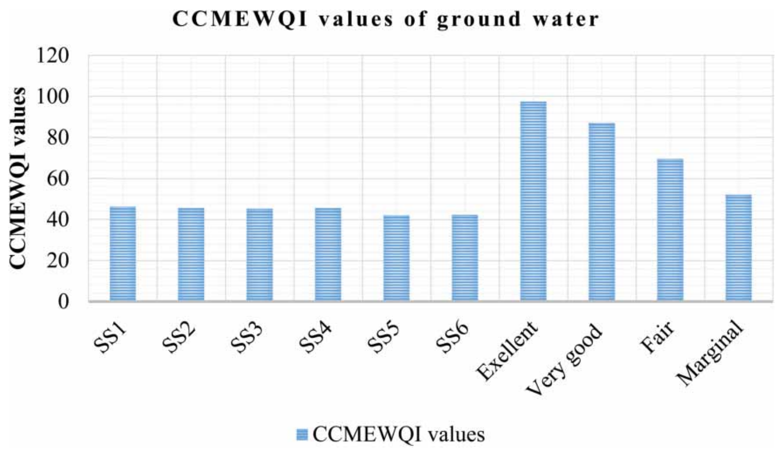

Figure 3 | Variations of WQI in the study area at different groundwater sample sites.

Calculation of Canadian council of Ministers of the Environment Water Quality Index (CCMEWQI) in the groundwater

Calculation of CCMEWQI for station one (SS_1)

$$F_1 = *100 = 3/14*100 = 21.43$$

$$F_2 = *100 = 8/84*100 = 9.524$$

$$\text{Excursion}_i = 100 - \left[\frac{2061}{1000}\right] - 1 + 100 - \left[\frac{1998}{1000}\right] - 1 + 100 - \left[\frac{2052}{1000}\right] - 1 + 100 - \left[\frac{9.33}{5}\right] - 1 + 100 - \left[\frac{9.21}{5}\right] - 1 +$$
$$100 - \left[\frac{8.99}{5}\right] - 1 + 100 - \left[\frac{0.059}{0.05}\right] - 1 + 100 - \left[\frac{0.051}{0.05}\right] - 1 = 778.183$$

$$nse = \frac{778.183}{84} = 9.2641$$

$$F_3 = \left(\frac{nse}{0.01nse + 0.01} = \frac{9.2641}{0.01 * 9.2641 + 0.01}\right) = 90.2573$$

$$\text{CCMEWQ} = 100 - \left[\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right] = 100 - \left[\frac{\sqrt{21.43^2 + 9.524^2 + 90.2573^2}}{1.732}\right]$$
$$= 100 - 53.842 = 46.2$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site one as marginal for *30th March 2011* to *20th August 2011*

Calculation of CCMEWQI for station two (SS_2)

$$F_1 = 3/14*100 = 21.43$$

$$F_2 = 9/84*100 = 10.71$$

$$\text{Excursion}_i = 100 - \left[\frac{2258}{1000}\right] - 1 + 100 - \left[\frac{2310}{1000}\right] - 1 + 100 - \left[\frac{1982}{1000}\right] - 1 +$$
$$100 - \left[\frac{9.02}{5}\right] - 1 + 100 - \left[\frac{8.87}{5}\right] - 1 + 100 - \left[\frac{9.03}{5}\right] - 1 + 100 - \left[\frac{8.76}{7.5}\right] - 1 +$$
$$100 - \left[\frac{8.82}{7.5}\right] - 1 + 100 - \left[\frac{8.43}{7.5}\right] - 1 = 875.598$$

$$nse = \frac{875.598}{84} = 10.424$$

$$F_3 = \left(\frac{10.424}{0.01 * 10.424 + 0.01}\right) = 91.25$$

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{21.43^2 + 10.71^2 + 91.25^2}}{1.732}\right] = 100 - 54.47 = 45.53$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling sit two as marginal for *30th March 2011* to *20th August 2011*

Calculation of CCMEWQI for station three (SS_3)

$$F_1 = 3/14*100 = 21.43$$

$$F_2 = 9/84*100 = 10.71$$

$$\text{Excursion}_i = 100 - \left[\frac{1966}{1000}\right] - 1 + 100 - \left[\frac{1898}{1000}\right] - 1 + 100 - \left[\frac{1954}{1000}\right] - 1 +$$
$$100 - \left[\frac{8.8}{5}\right] - 1 + 100 - \left[\frac{6.58}{5}\right] - 1 + 100 - \left[\frac{7.23}{5}\right] - 1 + 100 - \left[\frac{8.93}{7.5}\right] - 1 +$$
$$100 - \left[\frac{8.96}{7.5}\right] - 1 + 100 - \left[\frac{8.98}{7.5}\right] - 1 = 877.0773$$

$$nse = \frac{877.0773}{84} = 10.4414$$

$$F_3 = \left(\frac{10.44414}{0.01 * 10.4414 + 0.01}\right) = 91.26$$

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{21.43^2 + 10.71^2 + 91.26^2}}{1.732}\right] = 100 - 54.48 = 45.52$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site three as marginal for *30th March 2011* to *20th August 2011*.

Calculation of CCMEWQI for station four (SS_4)

$$F_1 = 3/14*100 = 21.43$$

$$F_2 = 9/84*100 = 10.71$$

$$\text{Excursion}_i = 100 - \left[\frac{2216}{1000}\right] - 1 + 100 - \left[\frac{2146}{1000}\right] - 1 + 100 - \left[\frac{2271}{1000}\right] - 1 +$$

$$100 - \left[\frac{8.75}{5}\right] - 1 + 100 - \left[\frac{7.02}{5}\right] - 1 + 100 - \left[\frac{7.73}{5}\right] - 1 + 100 - \left[\frac{7.6}{7.5}\right] - 1 +$$

$$100 - \left[\frac{9.08}{7.5}\right] - 1 + 100 - \left[\frac{9.28}{7.5}\right] - 1 = 876.2057$$

$$nse = \frac{876.2057}{84} = 10.43102$$

$$F_3 = \left(\frac{10.43102}{0.01 * 10.43102 + 0.01}\right) = 91.252$$

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{21.43^2 + 10.71^2 + 91.252^2}}{1.732}\right] = 100 - 54.4714 = 45.5286 \approx 45.53$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site four as marginal for *30th March 2011* to *20th August 2011*.

Calculation of CCMEWQI for station five (SS_5)

$$F_1 = 4/14*100 = 28.6$$

$$F_2 = 15/84*100 = 17.9$$

$$\text{Excursion}_i = 100 - \left[\frac{2252}{1000}\right] - 1 + 100 - \left[\frac{2298}{1000}\right] - 1 + 100 - \left[\frac{2263}{1000}\right] - 1 +$$

$$100 - \left[\frac{0.058}{0.05}\right] - 1 + 100 - \left[\frac{0.057}{0.05}\right] - 1 + 100 - \left[\frac{0.06}{0.05}\right] - 1 + 100 - \left[\frac{0.063}{0.05}\right] - 1 +$$

$$100 - \left[\frac{0.068}{0.05}\right] - 1 + 100 - \left[\frac{9.16}{7.5}\right] - 1 + 100 - \left[\frac{9.4}{7.5}\right] - 1 + 100 - \left[\frac{9.11}{7.5}\right] - 1 +$$

$$100 - \left[\frac{7.53}{7.5}\right] + 100 - \left[\frac{7.69}{7.5}\right] + 100 - \left[\frac{7.58}{7.5}\right] - 1 + 100 - \left[\frac{0.66}{0.1}\right] - 1 = 1458.74$$

$$nse = \frac{1458.74}{84} = 17.37$$

$$F_3 = \left(\frac{nse}{0.01nse + 0.01} = \frac{17.37}{0.01*17.37 + 0.01}\right) = 94.56$$

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right] = 100 - \left[\frac{\sqrt{28.6^2 + 17.9^2 + 94.56^2}}{1.732}\right]$$

$$= 100 - 57.97 = 42.03 \approx 42$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling five as poor for *30th March 2011* to *20th August 2011*.

Calculation of CCMEWQI for station six (SS_6)

$$F_1 = 5/14*100 = 35.71$$

$$F_2 = 11/84*100 = 13.1$$

$$\text{Excursion}_i = 100 - \left[\frac{2237}{1000}\right] - 1 + 100 - \left[\frac{2197}{1000}\right] - 1 + 100 - \left[\frac{2226}{1000}\right] - 1 +$$

$$100 - \left[\frac{8.12}{5}\right] - 1 + 100 - \left[\frac{7.37}{5}\right] - 1 + 100 - \left[\frac{8.27}{5}\right] - 1 + 100 - \left[\frac{0.051}{0.05}\right] - 1 +$$

$$100 - \left[\frac{8.5}{7.5}\right] - 1 + 100 - \left[\frac{9.03}{7.5}\right] - 1 + 100 - \left[\frac{8.87}{7.5}\right] - 1 + 100 - \left[\frac{0.67}{0.1}\right] - 1 = 1066.35$$

$$nse = \frac{1066.35}{84} = 12.695$$

$$F_3 = \left(\frac{12.695}{0.01 * 12.695 + 0.01}\right) = 92.7$$

$$\text{CCMEWQI} = 100 - \left[\frac{\sqrt{35.71^2 + 13.1^2 + 92.7^2}}{1.732}\right] = 100 - 57.85 = 42.15 \approx 42.2$$

The result obtained from the application of CCMEWQI has categorized the Chilanchil Abay watershed quality at sampling site six as poor for *30th March 2011* to 20th August *2011*. The overall results of CCMEWQI for all ground water samples of Chilanchil Abay watershed were summarized as follows:

Analysis in Chilanchil Abay watershed in Table 15 and Figure 3 shows the variation of WQI with CCME standard level to evaluate the status of existing groundwater quality in the study area. The calculated results obtained from all sampling sites of groundwater were showing four sample points as marginal and two sample points as poor for *30th March 2011* to *20th August 2011*. All the marginal status sample points are found in the upstream of waste disposal site. This indicates that water quality is frequently endangered or deteriorated; conditions often deviate from natural or desirable levels. This could be due to decaying plants and animals, agricultural fertilizers and open defecation activities. The remaining two poor status sample points were found downstream of the waste disposal site. This indicates that the water quality of these sampling sites is always endangered or deteriorated; conditions usually deviate from natural or desirable levels. Figure 3 shows that considering all sample sites, sample site five and sample site six have shown the worst quality in context of CCMEWQI. The reasons may include the migrations of leachate downstream from the dump site towards those two sample points.

Comparisons of the effect of open dump site on surface and groundwater quality of Chilanchil Abay watershed

The overall water quality assessment (ground and surface) of the Chilanchil Abay watershed was compared. The result is presented in Figure 4. As can be seen in Figure 4, the average values of standardized surface water quality parameters were higher than that of standardized values of the groundwater quality parameters. Subsequently, it can be conceivable to state that surface water quality was more influenced than groundwater quality by the dumping site leachate. For most sampling sites, this has been seen with the parameters of phosphate, chromium, TDS and electrical conductivity. The reason for surface water to be affected more than that of groundwater was because surface water is more readily exposed to pollutants caused by anthropogenic activity. Every anthropogenic activity started from the surface and then its first effect was applied on the surface phenomena. On the other hand, groundwater is less susceptible to different pollution than surface water because the soil and rock through which groundwater flows screen out most of the pollutants. This is by no means saying that groundwater is invulnerable to contamination since easily soluble chemicals are the primary candidates of groundwater pollution. This is similar with the work of P. Trivedi (Trivedi *et al.* 2008) who found surface water was more affected than groundwater by the introduction of external influences.

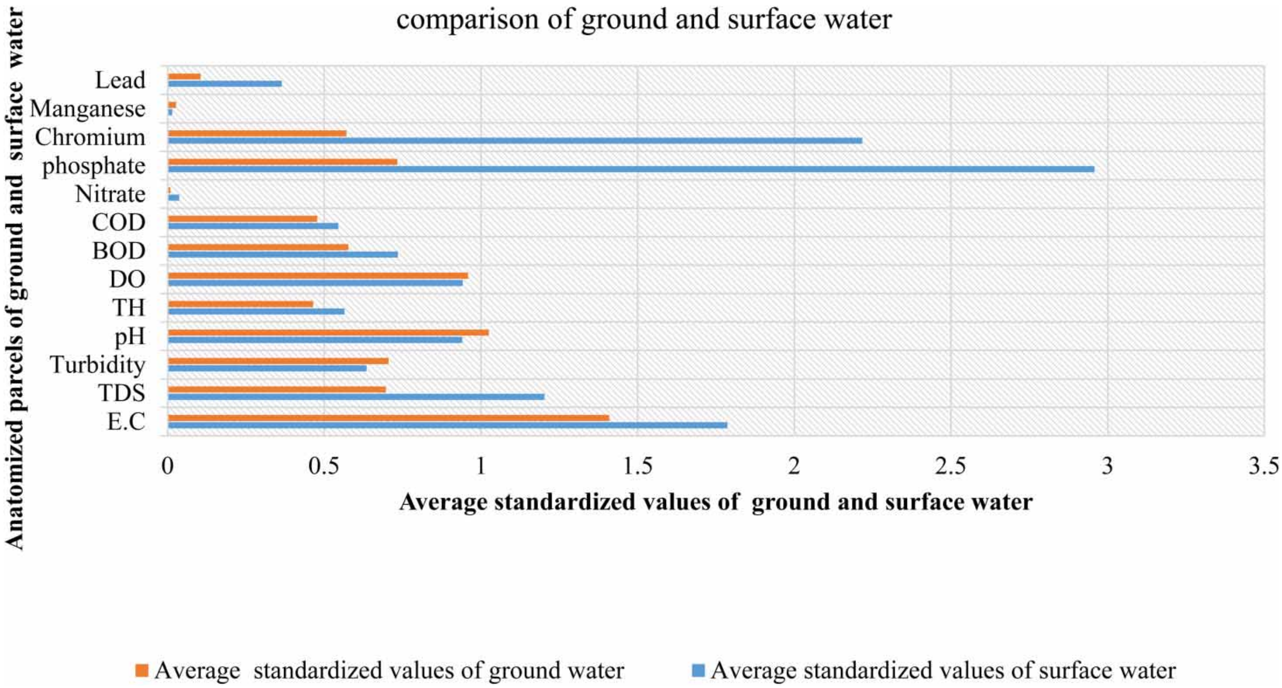

Figure 4 | Comparisons of the effect of the dump site on surface and groundwater quality.

CONCLUSION

According to the Canadian Council Ministers of the Environment Water Quality Index (CCMEWQI) the water quality of Chilanchil Abay watershed was categorized as poor and marginal.

The temporal and spatial variations of ground and surface water quality of Chilanchil Abay watershed was assessed following WHO quality parameters (January 2004) and Canadian water quality index (Khan *et al.* 2004) The analysis of physico-chemical properties, concentrations of heavy metals and nutrients recorded values show that TH, BOD, COD, Mn and Pb were within the acceptable limit (values of the objective in all the above tables) for both ground and surface water during the study time while the remains fluctuated with the seasons.

From the findings of the study, it assured that sample sites below the dump site were more affected than the sample points of upstream.

The aim of this study was to survey and assess the water quality in that watershed, especially close to the waste disposal site, to assess its impact on ground and surface water quality. Therefore, according to the CCMEWQI, all statuses of the samples sites were affected by the existing dump sites and other effects from around (like fertilizers, open efecations and other anthropogenic activities). Then data suggested that the dump site should be displaced from its current location or must be engineered in the way of landfill (currently it locates at the center of human settlements and agricultural fields).

ACKNOWLEDGEMENTS

The authors would like to thank Bahir Dar University, Bahir Dar Institute of Technology for technical supports of this project.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 7 August 2020; accepted in revised form 16 August 2021. Available online 30 August 2021