the Impact of Watershed Land Use on River Water Quality: Implication for Planning in the Case of Kebena River Watershed, Addis Ababa, Ethiopia

Kalkidan Asnake (kalkidan.asnake@eiabc.edu.et)
Fraunhofer Informationszentrum Raum und Bau
Hailu Worku
Ethiopian Institute of Architecture Building Construction and City Development
Mekuria Argaw
Center For Environmental Sciences, Addis Ababa University

Research

Keywords: Kebena river, Addis Ababa, land use land cover, water quality, sub-watershed

Posted Date: October 8th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-87208/v1

Version of Record: A version of this preprint was published on January 12th, 2021. See the published version at https://doi.org/10.1186/s40068-020-00208-y.

Abstract

Background: The impact of watershed land-use on surface water quality, especially in urbanized areas, has been investigated in numerous studies in developed countries, however, the issue is one of the under researched areas in developing cities of Africa. To study the impact of watershed land-use on surface water quality, we used the main land use types of the Kebena watershed from aerial photograph and collected river water samples during the dry and wet seasons for two consecutive years at different points from the river course. We calculated the share of each land use using ArcGIS and tested the water quality during each season. The variations in water quality parameters relating to the different land use types of the sub-watersheds were analyzed using ANOVA.

Results: Kebena watershed is mainly covered by 39.14% forest, 32.51% built-up area and 27.25% cultivated land. At sub-catchment level, Denkaka, (agriculture dominated) sub-catchment with 44.90 % cultivated land, Little Kebena, (forest dominated) sub-catchment, with 60.87% forest cover and Ginfle (urban dominated) sub-catchment with 90.44% built-up area were identified. The variations in water quality parameters relating to the different land use types of Kebena watershed revealed the significantly high seasonal relationship between the concentration of the water quality indicators during the dry season at ($P<0.001$, $P<0.05$). Furthermore, there is a strong positive relationship between the urban and forest dominated sub-catchments and water quality indicators during both the wet and dry seasons than agriculture dominated sub-catchment.

Conclusion: Integrating watershed planning with land use planning, therefore, becomes one of the vital tools to address water quality problems in a holistic manner to further prioritize restoration and protection strategies for specific sub-catchments. Thus, in the urban dominated sub-catchment, relocating riverfront communities, providing a well-designed sewage system, applying appropriate storm water management schemes, are some of the important measures while providing wide river buffers with various vegetation cover are necessary to minimize pollutants influx to the river from the agriculture dominated sub-catchment. Furthermore, in the forested sub-catchment, applying preventive measures to retain and enhance connectivity of the existing natural green spaces through open space planning, development and management schemes is crucial.

1. Background

The negative impact of watershed land use on water quality has been in discussion for a long time (Ding et al., 2015; Barbec, 2009; White and Greer, 2006; Findlay and Taylor, 2006; Goonetilleke et al., 2004; Brabec, Schulte, and Richards, 2002; Paul and Meyer, 2001; Klein, 1979). The impacts are observed mainly on water quality as caused by point and non-point pollution sources (Paul and Meyer, 2001). Point source pollution is the result of a direct release of pollutants from nearby known sources. Thus, increasing the impact of watershed land use on river water quality particularly with certain types of land uses such as settlements, institutions, agriculture fields, industries, water treatment plants, and mining fields that directly release their waste to rivers (Gyawali et al., 2013; Spanhoff et al., 2012; Hudak and Banks, 2006).

On the other hand, non-point source pollution is caused by poor stormwater management in a watershed, where most of the impacts are directly related to the increasing proportion of watershed imperviousness. Urban land-use features such as roof covers and road construction, which primarily change watershed land cover from pervious surface to impervious, changing the runoff water by increasing the volume of stormwater flow to rivers (Xu et al., 2019; Wright, Liu, et al. 2016; Findlay and Taylor, 2006; Doerfer and Urbonas, 2004; Arnold and Gibbons, 1996; Leopold, 1968). This land use change results in high amount of urban runoff containing high levels of pollutants affecting the water quality of the receiving water bodies (Lim and Lu 2016; Ding et al., 2015). In line with this, the impact of urbanized watershed on stream water quality impairment is first observed when imperviousness reaches 10-12% and increases with the change in land use, starting to become severe when the imperviousness reaches 30% (Li et al., 2008; Arnold and Gibbons, 1996; Klein, 1979). Arnold and Gibbons (1996) further discussed that the amount of runoff doubles when catchment impervious surface cover reaches between 10–20 percent, triples between 35–50 percent, and intensifies to more than five times when imperviousness increases to 75–100 than in a forest covered watershed land use.

The high rate of watershed urbanization in developing cities exerts extreme pressure on urban rivers as urban centers are often expanding without proper planning and adequate waste disposal and infrastructure facilities provision (Liang et al., 2017; Yabe et al., 2010). Thus, urban rivers in developing cities are threatened by high rate of water pollution and rapid loss of biodiversity.

Under normal circumstances, urban plans guide urbanization through the provision of land use plans, road network plans, different infrastructural provision plans and implementation strategies and procedures (Patricia et al., 2013; Carter, 2007). Consequently, the nature and location of development which mostly is decided by urban planners significantly influences both the generation and resolution of environmental problems (Patricia et al., 2013; Barbec, 2009; Carter, 2007). Though urban plans play a vital role to balance the various development needs and the provisional capacity of available land, it is not common to integrate anticipated environmental pressures and further study the impacts of upcoming developments on natural resources (Carter, 2007). This is especially true with river water quality related issues that are addressed by a different entity apart from major urban planning factors, which have greatly affected rivers as most projects originate from urban planning decisions (Cettner, et al., 2013; Patricia et al., 2013; Carter, 2007).

To maintain the balance between nature conservation and development demand in an urban setting, watershed planning and management is becoming a key approach to minimize the impact of watershed land use on surface waters. Historically, watershed planning and management were used to solve flood-related problems (Ward et al., 2012). Currently, however, attempts are being done to study the relationship between land use, the flow and storage of water, and water quality (Doerfer and Urbonas, 2004). Moreover, habitat conditions, ecology, and community values are taken into consideration as the vital aspect of watershed-based planning and management approach (EPA, 2013; EPA, 1995). Watershed planning and management also enhance program efficiency, improve coordination among institutions, and balance the allocation of resources and funding (Browner, 1996; Doerfer and Urbonas, 2004).

In Addis Ababa, rivers and riversides are among the natural resources that are negatively affected by the rapid watershed urbanization (Worku and Giweta, 2018; AACSPPO, 2017; Yohannes, and Elias, 2017; Mazhindu et al., 2012; Gebre and Rooijen, 2009; Alemayehu, 2001).Land-use change and deforestation in Addis Ababa have resulted in high level of river water pollution, which has become a threat to human health and native biodiversity causing habitat loss and fragmentation (AACSPPO, 2017; Weldegebriele et al., 2012; Beyene et al. 2009). Kebena River is one of the main tributaries of the Awash River basin, originating from the northern tip of the Entoto Mountain in Addis Ababa. Despite the fact that many people use Kebena river water for various domestic purposes, the river is continually exposed to contamination by solid and liquid wastes from different sources (Worku and Giweta, 2018; Seyoum et al., 2017).

Thus, the aim of this study is to examine the impact of watershed land use on Kebena river water within its spatial and seasonal variation. Furthermore, the study assessed the river's water pollution linkage with the dominant land-use types within the three catchments of Kebena watershed. The findings of the study are, therefore, utilized to forward pertinent recommendations for major watershed-level planning and management interventions to improve water quality of the Kebena River.

2. Methodology

2.1 Description of the study Area

This study was conducted in the Kebena river watershed draining the upper most central part of the city of Addis Ababa (Fig. 1). Generally, the Addis Ababa river catchments are drained by two major river systems such as *Tinishu* Akaki (Little Akaki) and *Tiliku* Akaki (Great Akaki) rivers. The two rivers originate from the Entoto Mountain chains and flow down to the man-made Lake, the *Aba Samuel* water reservoir, at the lower end of the City (Gebre & Rooijen, 2009; Beyene et al., 2009). Kebena River is characterized by mountainous landscape that dissects the central part of the City and its watershed is situated in the northern-central part of the city, within a geographical location between of 8° 9' 50"N - 9° 6' 60"N latitude, and 38° 45' 30" - 38° 49' 30"E longitude (Fig. 1). The total estimated area is about 5,150 ha with an elevation range of 2000 to 3200 m.a.s.l.

The flow of water in the rivers varies during the dry and wet seasons, thus varying the pollution character. In Addis Ababa, the dry season extends from December to May while the rainy season extends from June to September. During the dry season, the city experiences an average temperature of 6°C to 29°C. There is also a short rainy season that falls between February to March, during this period the city experiences mild rains. Whereas, the long rainy season is from June to September and the largest amount of rain falls during this period, which averages to about 900 mm as calculated from 30 years of meteorological data (Fig. 2).

2.2 Land use and Watershed Analysis

Major land uses in the *Kebena* watershed were mapped using manual digitization of rectified aerial photograph of the year 2016 to categorize the land use types using ArcGIS 10.1 software. With the assumption that different land use types have varying level of potential effects on water quality, the land use types were categorized into four groups based on the dominant land use : (1) forested land use including natural forest, Eucalyptus globulus plantation, and riverine vegetation, (2) built-up area (impervious surfaces) accommodating residential, light industries, hospitals, schools other land uses (3) Cultivated land (pervious surfaces including grassland, and agriculture land), and (4) bare land (degraded bare soil/rock surface) (Figure 3).

The study also used a 30m Digital Elevation Model (DEM) to determine the flow-path directions of the three sub-watersheds using the hydrology tool of spatial analyst tool set in ArcGIS version 10.1. The outlet points of the sub-watersheds were used as sampling sites whereby, the flow-path-direction grid cells were used to produce upstream catchment for each site. Based on the result of the hydrology tools, three sub-watersheds were identified as Urban, Agriculture, and Forest dominated sub-watersheds within Kebena watershed. The impact of the lower part of the main watershed is included as part of Kebena watershed. Databases have been transformed into a common digital format, projected onto a common coordinate system (UTM) and analyzed as vectors in ArcGIS (Sliva, and Williams, 2001).

2.3 Water Quality Analysis

Water quality tests were conducted at the main watershed and sub-watershed levels. Eight sampling points were selected to study the impact of watershed land use on river water quality. Seasonal sample collection was conducted in two consecutive years and a total of 128 water samples were collected during the two major seasons of the years 2016 and 2017. Wet season samples were taken between June and August while dry season samples were taken between January and March.

Water samples were collected at a depth of 20 cm below the water surface and at 1.5 m distance from the edge of the land surface into the mid of the river using a 2L polyethylene plastic bottle. The bottles were rinsed very well with sample water and samples were taken by dipping the opening of the sampler upslope. The water samples were stored in iceboxes until the analyses were conducted. Samples were taken to Addis Ababa Environmental Protection Authority laboratory within 4 hours after collection and analyzed for selected water quality parameters.

Acid-cleaned polyethylene gloves were used while handling all materials during sample collection and analysis. A total of 10 parameters were selected to assess the pollution level of the river water. These were pH, EC, TDS, TSS, BOD, COD, Total Nitrogen, Total Phosphorous, Ammonia, and Chloride. All the parameters were analyzed in the laboratory involving standard experimental protocols as outlined in APHA (2005). The pretreatment and the determination of the parameters in the laboratory followed national standard methods of examining water and wastewater, which were provided by the Environment, Forest and Climate Change Commission, Ethiopia. The values of the parameters that are presented in this paper are the means of composite analyses. The mean values of the water sample test results were calculated and compared to international and local water quality standards for various purposes. Furthermore, the pollution level of Kebena river water was examined.

2.4 Statistical Analysis

Statistical analyses were performed to study the relationships between land-use variables and water quality parameters. A one-way ANOVA test was used to compare mean values of water quality parametersamong the sub-watersheds for different water quality indicators for the dry and wet seasons. Independent Test was conducted to compare the mean values of the different water quality indicators for the wet and dry seasons. Multiple regression analysis was applied to determine whether watershed land use factors have positive or negative influence on separate water quality indicators and how strong this interaction is using three predictor land use variables (agricultural, forested, and urban land use variables).

3. Results

3.1 Watershed Land Use types and distribution

Kebena river watershed accounts for a total area of 5,247.60 ha of land of which 39.14% is forest composed of *Eucalyptus globulus* plantation and riverine vegetation. The second dominant land use in the watershed is the settlement or built-up area covering 32.51%. Thirdly, the Kebena watershed contains cultivated land use accounting for 27.25% of the total area, while the remaining 1.1% of Kebena watershed is considered as bare land consisting of bare soil and rocks.

Along with the other sub-watersheds, the agriculture dominated sub-watershed (Denkaka sub-watershed) covers a total area of 2474.20 ha of land, out of which 44.90% is field crop, 34.14% forest, 19.17% built-up area, and 1.78% bare land. Likewise, the forest dominated sub-watershed in the middle (*Little-Kebena* sub-watershed), is predominantly covered with 60.87% of natural forest mixed with *Eucalyptus globulus* plantation covering a total area of 1010.10ha (Table 1). The second-largest land use within the sub-watershed is the built-up area which covers 21.50% of the total land followed by cultivated land and bare land accounting for 17.00% and 0.63%, respectively. In addition to the dominant land use type, which is forested area, this sub-watershed is covered by a highly congested settlement, largely occupying the lower part of the sub-watershed covering areas of the riverbanks. The urban dominated sub-watershed with a total area of 387 ha of land accommodates 90.44% of built-up area, 7.49% of field crop including urban farms, 1.5% of forest including parks and riverine vegetation, and 0.52% of bare land (Table 1).

3.2 Seasonal Variations in Water Quality of the Kebena watershed

The result of the analysis showed that there are significantly high seasonal variations in the concentration of the water quality indicators. As shown in Table 2 below, the river water carries significantly higher loads of pollutants during the dry season than in the wet season ($P<0.001$, $P<0.05$). Accordingly, mean values of all parameters except TSS, COD, and BOD have variation at P-Value of at 0.000.

The mean values of TSS, EC, Ammonia, and TN are significantly higher during both the wet and dry seasons compared to surface water quality standards set by WHO, which is 25 mg/l, 0.60 – 0.18µs/cm, 1.5 mg/l, 10 mg/l, respectively. On the contrary, Chloride and COD showed significantly lower values in the wet season compared to surface water quality standards set by UNEP, and WHO which is 200-300mg/l and 250mg/l, respectively (Table 2).

3.3 Seasonal and spatial variations of water quality in the sub-watersheds

In aquatic life, pH is an essential chemical limiting factor if excessively acidic or alkaline streams can interfere with aquatic organisms' biochemical reactions, which either harm or destroy stream organisms (Dumago et al., 2018). The results from this study show that in the wet season, the mean pH level at the source of the river within the forest watershed is 6.73. The lowest mean value of pH was recorded in the agriculture dominated Denkaka sub-watershed, which is 5.64, followed by forest dominated little-Kebena sub-watershed with a value of 5.92 and urban dominated Ginfle sub-watershed with a value of 6.64. Besides, in the dry season, the mean value of the river water at the source is 7.04, whereas lower pH value was reported to be 7.65 in the urban dominated sub-watershed of Ginfile, 8.00, in forest dominated sub-watershed of (Little-Kebena) and 8.08 in agricultural dominated sub-watershed of Denkaka.

Electrical Conductivity (EC) is a capacity of how easily electrical current can pass through water, hence depending on the presence of charged ions, whereas Total Dissolved Solids (TDS) contain mineral and salt impurities dissolved in water (Moore, Richards, and Story, 2008; Dumago et al., 2018). These impurities, when present in high quantities, affect the quality of surface waters to provide various ecosystem services. Total Suspended Solids also affect water color due to higher water TSS concentration, higher turbidity worsens water clarity (Dumago et al., 2018).

Accordingly, the result showed that EC and TDS values in the three catchments and Kebena watershed are higher with no noticeable variations during the dry season, and the ANOVA result also reveals ($F=0.79$ and 0.486 for EC and TDS, respectively, while p-value is > 0.05).

However, the TSS value displays substantial variability with F=25,56 and p-value < 0.01 during the dry seasons. On the other hand, during the wet season, the findings of ANOVA showed that the mean values of both EC, TDS and TSS display major differences across the three catchments and Kebena with F = 122,51, 35,87 and 22,77 respectively, and p-value < 0,01).

COD is the amount of total oxygen needed to oxidize into carbon dioxide and water both biologically accessible and inert organic matter (Lee and Nikraz, 2015), mainly used to determine the organic pollutant present in the river water. BOD on the other hand is the calculation of the amount of oxygen biologically required to break down organic matter under aerobic conditions (Lee and Nikraz, 2015), which is a widely used for measuring organic pollution of surface waters. The results, therefore, indicated that at the source of the Little-Kebena catchment, the value of COD accounts for 14 mg/l and 12mg/l while the mean value of BOD is registered to be 2.4 mg/l and 10.8 mg/l during the wet and dry seasons, respectively.

The value of COD increase to 55 mg/l and 34mg/l, during the wet and dry seasons, respectively, at the lower end of the catchment. Similarly, the value of COD at the lower part of Denkaka catchment increases in both the rainy (39mg/l) and dry seasons (46mg/l). Moreover, at the Ginfle catchment, the value of COD is registered to be 114.00 mg/l during the rainy and 157.00 mg/l during the dry seasons. The BOD value also increases for the two catchments during the dry season, 40.2mg/l for Little-Kebena and 23mg/l for Denkaka catchments, however, the lowest value is registered for Ginfle catchment which is 12.1mg/l.

The ANOVA result also shows the significant variation between the three catchments, Kebena watershed and COD results during both the wet and dry seasons with $F = 165.74$ and 287.12, respectively and $p\text{-value} < 0.01$). Furthermore, the ANOVA result revealed significant differences between the three catchments, Kebena watershed and BOD values during the wet and dry seasons with $F = 287.12$, and 754.83, respectively and $p\text{-value} <0.001$.

During the wet and dry seasons, the mean value of Ammonia at the source of Little-Kebena catchment was found to be 1.25, and 0.001 mg/l, respectively. During the wet season, higher value was registered at the Ginfle catchment with 18.25 mg/l, whereas during the dry season, higher level of Ammonia 138.1mg/l was recorded at Ginfle catchment. The ANOVA result also shows the significant disparity between the three catchments, Kebena watershed and Ammonia results during both the wet ($F = 648.15$, $p\text{-value} <.01$) and dry ($F = 32.94$, $p\text{-value} <0.001$) seasons.

According to the results, the mean values of Total Phosphorous (TP) at the source of Little-Kebena are found to be 0.5mg/l and 8.6mg/l during the wet and dry seasons, respectively. While the results of Total Nitrogen (TN) are registered to be 14 mg/l and 9 mg/l during the wet and dry seasons, respectively. The results of TP showed an increase towards the lower part of Little-Kebena and Ginfle catchment while decreasing in Dekaka catchment. With regards to TN the value was found to be lower during the rainy season in all the three sub-watersheds with a mean value of 4.1, 3, and 10mg/l in Little-Kebena, Denkaka and Ginfle sub-watersheds, respectively. During the dry season, these values increased intensely in all three catchments and Kebena watershed whereby the highest mean value was recorded at Ginfle catchment with a value of 129mg/l.

The ANOVA result also shows the significant relationship between the three catchments, Kebena watershed and TP results during wet seasons with ($F = 46.65$, $p\text{-value} < 0.001$), where the result of Ginfle catchment was found to be very high with 1.55mg/l. During the dry season The ANOVA result also confirmed to this significant variation with ($F = 11.58$, $p\text{-value} < 0.001$), where a high value was recorded from Ginfle catchment with 16.09 mg/l. Furthermore, the ANOVA results confirmed the significant differences between the three catchments, Kebena watershed and of TN during wet seasons ($F=47.05$, $p\text{-value} < 0.001$), and dry seasons with ($F = 25.77$, $p\text{-value} < 0.001$).

The effect of Chloride concentration or conductivity in surface waters is considered as general urban impact indicator (Paul and Meyer, 2001). The result of the Chloride analysis at the source of Little Kebena was found to be 22.2 and 10.4 during the wet and dry seasons respectively. The high level of Chloride 102.8mg/l during the dry season is registered in the Denkaka catchment while the lowest value was recorded to be 79.2mg/l at Ginfle catchment. During the rainy season, a high amount of Chloride, i.e., 78.8mg/l was recorded in Gifle catchment while the lowest was found to be 36.61mg/l at Denkaka watershed. The ANOVA results also revealed the strong differences between the three catchmenets, Kebena watershed and Chloride at ($F=110.34$ and $p\text{-value} <0.001$) during the wet and at $F= 35.66$ and $p\text{-value} <0.001$) during the dry seasons

3.4 Watershed land use and water quality indicators

Compared to water quality indicators at the source of the forest dominated catchment, the Urban dominated (Ginfle) and the forest dominated (Little-Kebena) sub-watersheds appeared to have the greatest effect on water quality during both the wet and dry seasons than the agriculture dominated (Denkaka) sub-watershed (Table 4). During the wet season, the Ginfle sub-watershed showed a strong positive relationship with all the water quality indicators except pH. While, forest dominated sub-watershed showed a positive relationship with all the water quality indicators except pH, TN, and TP. In contrast, TN showed a negative relationship with all the watersheds at $P < 0.01$ level, with R^2 value of 0.86. Whereas TP showed a strong negative relationship with all the sub-watersheds except Ginfle with R^2 of 0.76, and pH showed a strong negative relationship with (Little-Kebena) and Denkaka sub-watersheds at s $P < 0.1$ level.

The urban dominated sub-watershed appeared to have the greatest effect on water quality (Table 4). The TDS, TSS, EC, Ammonia, TN, TP, Chloride and COD showed strong positive relationship at $P < 0.01$. The pH showed a positive relationship at $P < 0.05$, while BOD showed no relationship. Forest dominated sub-watershed showed higher value of water quality indicators during the dry season in which the pH, TDS, EC, Ammonia, T-N, Chloride, COD, and BOD were strongly and positively related (Table 4). The agriculture dominated sub-watershed though revealing lower water quality indicators during the dry season, still exhibits a strong positive relationship with pH, TDS, EC, Ammonia, TN, Chloride, COD, and BOD at $P < 0.01$ level.

In general, the Kebena water quality result at the end of the watershed when compared with the source revealed higher more serious effect during both the wet and dry seasons since all the water quality indicators showed strong positive relationship except BOD and pH. The latter two parameters were found to be negatively related with the watershed's land use.

4. Discussion

4.1 Seasonal variations of water pollution in the Kebena River

The water quality in the Kebena River was found to be deteriorated during the wet and dry seasons due to pollutants originating from various sources in the watershed. The results in this study are in agreement with earlier studies in the watershed (AACSPPO, 2017; Worku and Giweta, 2018). The clear deterioration in the dry season water quality suggest that perhaps the pollution sources are mainly from point sources located at different parts of the river course (Worku and Giweta, 2018). This is possibly true because in most of the places along the river course, liquid wastes from nearby residential settlements and other land uses are directly connected to the river through open ditches and road side drainage lines, aggravating the impact during the dry season as there is no rain to dilute the river water.

During the wet season, the mean value of pH (6.23) of Kebeba river was below the range of the permissible limits which is 6.5-8.5/9, (DENR, 2016; WHO, 2004; EPA, 2003) showing mainly of acidic character assumed to be resulting from the heavy rain during the wet season. This limits the potential of the river water to deliver various ecosystem services during the rainy seasons. However, during the dry season, the average pH value of the river water is 7.87 which makes it suitable to provide various ecosystem services (WHO, 2004).

The fact that mean values of TSS, EC, Ammonia, TP, and TN are significantly higher during both the wet and dry seasons compared to surface water quality standards is assumed to be associated with high amount of direct sewage discharges (U. S. E.P.A., 2002; Gibb, 2000). Furthermore, the value of EC is highly affected by temperature which validates the higher value of EC in Kebena river during the dry season (Moore, Richards, and Story, 2008). Large nutrient loads of nitrogen (TN) and phosphorus (P) can have somewhat specific routes, partially due to land use, building drainage and impermeable paved surfaces, and leaf litter dropping from cultivated trees, (Teurlincx et al., 2019;). The potential sources of phosphorus specially during the dry seasons in urban catchments might be related to wastewater disposals, and in-stream bathing and laundry activities (Dumago et al., 2018; Pieterse, Bleuten and Jørgensen, 2003; Paul and Meyer, 2001).

On the contrary, Chloride and COD showed significantly lower values in the wet season compared to surface water quality standards, this might be related to the diluting effect of the rain water during this season which affects the concentration of salts and other minerals (Giglioli, and King, 1966).

4.2 Relation between watershed land use and water quality

The study also compared water quality indicators from source of the forest-dominated catchment of the Little Kebena River with samples collected from the lower point of Little-Kebena watershed itself, the urban-dominated Ginfle catchment, and the agricultural-dominated Denkaka catchment in order to identify the catchment with a higher effect on the water quality of the river. Accordingly, the result revealed the strong positive relationship between the urban dominated catchment land use and various water quality indicators such as, Total Nitrogen, Total Phosphorous, Chloride, COD and BOD, are observed during both the dry and wet seasons. The high amount of TP observed in Little-Kebena and Ginfle catchments during the wet seasons, therefore, mainly is the result of the existence of large impervious surfaces coverage within the catchments. Therefore, the water quality of Ginfle river revealed high water pollution during both the wet and dry seasons, which is highly supported by many studies that concluded that water quality of rivers found in highly urbanized watersheds are strongly positively related to various water quality parameters (Brabec, 2009; Sliva and Williams, 2001). According to earlier studies, high runoff in urban watersheds is directly related to high watershed imperviousness; Schueler (1995) and Klien (1979) conversed that the degradation of the river water quality is extreme to the point where it is almost unavoidable at 30% of the imperviousness of watersheds.

Contrary to most researches such as Ding et al., (2015), Sliva and Williams (2001) the forest dominated sub-watershed with 60.87% of forest cover indicates a positive relationship with a number of water quality indicators such as Chloride, COD and BOD, and TSS during the wet season while pH, TDS, EC, Ammonia, TN, Chloride, COD and BOD show strong positive relationship during the dry season. The strong positive relationship of the river water with the above mentioned indicators could be attributed to the discharge of liquid waste from closely developed settlements in the middle and lower catchments of Little Kebena River, as discussed by (Brabec, 2009); whereby the location of development within a given watershed plays an important role in water quality variability in addition to the percentage of watershed imperviousness. The structural plan also confirmed that some parts of the upper watersheds are occupied by informal settlements and industries (AACSPPO, 2017). Land degradation is also another major challenge aggravating soil erosion, specially within the Eucalyptus plantation (AACSPPO, 2017) which explains the large amount of TSS and TDS in Kebena River water.

The agriculture dominated sub-watershed with 19.17% and forest dominated sub-watershed with (21.50%) of their land being built-up, lie within the imperviousness cover ratio of 12-30% where the impact of the watershed is considered as minimal. Thus, controlling further impervious surface increment of the watersheds, while delineating proper river buffer zones, guiding upcoming developments, and implementing proper water pollution instruments is significantly crucial for the improvement of Kebena river water quality. Planning documents along with Building Permit Directives can be used as tools to guide and monitor development and imperviousness ratio of institutions and individual compounds.

4.3 Planning Implication to water pollution mitigation in the urban settings

The City Structural Plan confirmed that high pollution of river waters emanates from domestic and industrial wastewater discharges as well as storm runoff, thus, suggested various ways to prevent pollution of rives (AACSPPO, 2017). In line with this, the structure plan outlined that one of the effective ways to lower point source pollution influx to Kebena river catchments is by introducing new and upgrading of existing Waste Water Treatment Plants (WWTPs) (Paul and Meyer, 2001; Björklund, 2015). Furthermore, the structure plan delineated river buffer zone around the rivers of Addis with the width of 10-30m to be covered with indigenous trees and shrubs, the structure plan also forwarded a way of considering the slope of the buffer zone and various ways of developing the sloped riversides (AACSPPO, 2017).

However, the suggested river water pollution prevention methods lack a watershed level perspective that will contribute to the fragmented and site-specific river management gaps of the study area. More importantly, the proposed environmental solutions of the Structural Plan are not synergized with the current and proposed land use, road networks and other planning features. This highly demeans the contribution to the planning decisions to prevent the river water pollution which is one of the main challenges of the city. Watershed planning, therefore, becomes as one of the vital tools to addresses water quality problems in a holistic manner by fully assessing the potential contributing causes and sources of pollution, then prioritizing restoration and protection strategies to address these problems (Ding et al., 2015; Arnold and Gibbons, 1996).

In the case of the Kebena river watershed, different watershed level planning approaches are required for the three sub-catchments so as to address the varying issues. For instance, in Ginfle catchment where 90% of the watershed is built up, there is significant need for a comprehensive watershed planning that emphasizes on preventing further river degradation while focusing on site level design that reduces runoff and imperviousness, (Arnold, and Gibbons,1996). Designing riversides in a manner that removes and cleanses much of the stormwater pollution that comes from the city before it joins the river is vital (Prominski et al., 2015). Furthermore, planning solutions should emphasize on emission reduction and enhancement of ecosystem conservation, as one of the Dublin Principles of 1992 (ICWE, 1992) which concerns river basin management at the lowest appropriate level (Kemper et al., 2007). In line with this, it is necessary to remove polluting land uses, incorporate open ditches, small streams, and roads with environmentally suitable storm water management network, and establish adequate river buffer while reconnecting green patches within the catchment. Furthermore, it is crucial to incorporate water pollution mitigation schemes into urban planning decisions through provision of compact development approach, and brown field development approaches to reduce natural landscape composition fragmentation (Xu et al., 2019), and riparian buffers development to control further increment of impervious surfaces (Xu et al., 2019; Chouli, Aftias, and Deutsch., 2007; Mander et al, 1997).

With regards to Little-Kebena catchment, where there is lower imperviousness ratio, river pollution mitigation measures should focus on preventive measures to retain the existing natural green spaces through open space planning, development and management schemes (Arnold, and Gibbons,1996). Moreover, location of development within the catchment plays a significant role in affecting water quality in an urbanized watershed whereby upland land use are critical in determining overall stream function, degradation, and rehabilitation potential Booth and Jackson (1997) and Barbec (2009). Thus, in this catchment, there is a possibility of extending the forest in the upper catchment to the lower catchment by limiting the various land uses that are polluting the river.

In Denkaka catchment, on the other hand, there is a crucial need for the provision of large river buffer zones to control runoff pollution coming mainly from crop fields, and settlements developed close to the river.

While developing watershed planning is crucial to preventing urban river pollution, its contribution will be limited if not adequately integrated with urban plans to facilitate its implementation and ensure its sustainability (Bernhardt and Palmer, 2007). Therefore, the findings of this study suggest that land use planning need to be combined with scientific analysis of land uses and possible sources of pollutants in order to achieve effective restoration and maintenance of river water quality.

5. Conclusions

The findings have indicated that Kebena river watershed, has a highly polluted river water, which limits its potential to deliver various ecosystem services. The overall finding revealed that pollutants originating from various sources (possibly from both the point and non-point sources) in the three sub-catchments are causing the water quality degradation of the river water.

Pollution in the Ginfle sub-watershed, where 90% of the sub-watershed is covered by built-up area, is very high both in the wet and dry seasons. In this catchment, the main causing factors are the direct discharges of sewage loads from residential houses, light industries, schools, open defecations and unmanaged runoffs. Pollutant influx from Little-Kebena and Denkaka sub watersheds also have their significant share in polluting the Kebena river.

The findings in this study can be considered as an addition of new knowledge to the river restoration research in order to understand how watershed landuse impacts river water quality in urbanizing cities. It may further indicate that small projects in the future, if not well studied and integrated at watershed level may not be effective in protecting river water pollution in the City and in the country at large.

The findings in this study can also be considered as an addition to policymakers in their decision-making process on how to integrate the crucial role of watershed planning into overall city land use planning activities in general and surface water quality issues in particular. Finally, future research should focus on developing tools, which help to transfer the main principles of watershed planning into practice. Further research can be conducted to identify and integrate the impact of landscape characters of sub watersheds such as slope, vegetation, and soil characters in addition to land use. Such studies will significantly advance our understanding on the integration of watershed planning principles into current river restoration activities in the country in particular and more widely in similar urban settings elsewhere.

List Of Abbreviations

If abbreviations are used in the text are defined in the text at first use.

Declarations

Ethics approval and consent to participate

“Not applicable”

Consent for publication

“Not applicable”

Availability of data and materials

All data and materials applied for the research are presented in the main paper.

Competing interests

“The authors declare that they have no competing interests”.

Financial competing interests

“Not applicable”

Authors' contributions

Mrs. Kalkidan (main author) and Professor Hailu first conceived of the presented idea. While I (Kalkidan) developed the theory, performed the computations and wrote the manuscript with support from Dr Mekuria who verified the analytical methods and proof read and edited the paper several times. Consequently, Professor Hailu supervised the process of the whole project.

Acknowledgements

We would like to thank the water quality analysis experts at the lab for their helpful assistance, and all the people who were involved during water sample collection.

References

Addis Ababa City Administration Structure Plan Project Office, 2017. Addis Ababa City Revised Structure Plan Executive Summary.

Alemayehu, T., 2001. The impact of uncontrolled waste disposal on surface water quality in Addis Ababa, Ethiopia. SINET: Ethiopian Journal of Science, 24(1), pp.93-104.

American Public Health Association, American Water Works Association, Water Pollution Control Federation and Water Environment Federation, 1920. Standard methods for the examination of water and wastewater. American Public Health Association.

APHA (2005) Standard methods for the examination of water and waste water, 21st edn. American Public Health Association, Washington, DC.

Arnold, C. and Gibbons, C., 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. Journal of the American Planning Association, 62(2), pp.243-258.

Beyene, A., Addis, T., Kifle, D., Legesse, W., Kloos, H., Triest, L., 2009. Comparative study of diatoms and macroinvertebrates as indicators of severe water pollution: Case study of the Kebena and Akaki rivers in Addis Ababa, Ethiopia. Ecological Indicators 9, 381–392. doi:10.1016/ j. ecolind.2008.05.001

Björklund, V., 2015. Water quality in rivers affected by urbanization: a case study in Minas Gerais, Brazil. Student thesis series INES.

Booth, D.B. and Jackson, C.R., 1997. Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation 1. JAWRA Journal of the American Water Resources Association, 33(5), pp.1077-1090.

Brabec, E., Schulte, S. and Richards, P. (2002). Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. Journal of Planning Literature, 16(4), pp.499-514.

Brabec, E.A., 2009. Imperviousness and land-use policy: Toward an effective approach to

Bernhardt, E.S. and Palmer, M.A., 2007. Restoring streams in an urbanizing world. Freshwater Biology, 52(4), pp.738-751.

Browner, C.M., 1996. Watershed Approach Framework. US EPA, Office of Water EPA 840, S96-001.

Cettner, A., Ashley, R., Viklander, M. and Nilsson, K., 2013. Stormwater management and urban planning: Lessons from 40 years of innovation. Journal of Environmental Planning and Management, 56(6), pp.786-801.

Chouli, E., Aftias., E. and Deutsch, J.C., 2007. Applying storm water management in Greek cities: learning from the European experience. Desalination, 210(1-3), 61-68.

Doerfer, J.T. and Urbonas, B.R., 2004. Urban Watershed Master Planning for Stream Protection in the Denver Metropolitan Area. In Protection and Restoration of Urban and Rural Streams (pp. 51-60).

Ding, J., Jiang, Y., Fu, L., Liu, Q., Peng, Q. and Kang, M., 2015. Impacts of land use on surface water quality in a subtropical River Basin: A case study of the Dongjiang River Basin, Southeastern China. Water, 7(8), pp.4427-4445.

Dumago, S.W.L., Puno, G.R. and Ingotan, S.S., 2018. Water quality assessment in various land use and land cover of Muleta watershed Bukidnon, Philippines. J. Biol. Environ. Sci, 12(3), pp.201-209.

Findlay, S.J., Taylor, M.P., 2006. Why rehabilitate urban river systems? Area 38, 312–325. doi:10.1111/j.1475-4762.2006.00696.

Gebre, G. and Van Rooijen, D.J., 2009. Urban water pollution and irrigated vegetable farming in Addis Ababa.

Gibb, S.W., 2000. Ammonia. In: Nollet, L.M.L. (Ed.), Handbook of Water Analysis. Marcel Dekker, Inc., NewYork, USA.

Giglioli, M.E.C. and King, D.F., 1966. The mangrove swamps of Keneba, Lower Gambia river basin. III. Seasonal variations in the chloride and water content of swamp soils, with observations on the water levels and chloride concentration of free-soil water under a barren mud flat during the dry season. Journal of Applied Ecology, pp.1-19.

Goonetilleke, A., Thomas, E., Ginn, S. and Gilbert, D., 2005. Understanding the role of land use in urban stormwater quality management. Journal of environmental management, 74(1), pp.31-42.

Gyawali, S., Techato, K., Monprapussorn, S. and Yuangyai, C., 2013. Integrating land use and water quality for environmental based land use planning for U-tapao river basin, Thailand. Procedia-Social and Behavioral Sciences, 91, pp.556-563.

Hudak, P.F. and Banks, K.E., 2006. Compositions of first flush and composite storm water runoff in small urban and rural watersheds, north-central Texas. Urban Water Journal, 3(1), pp.43-49.

Kemper, Karin E., and William Andrew Blomquist. Integrated river basin management through decentralization. Edited by Ariel Dinar. Berlin: Springer, 2007.

Klein, R.D., 1979. Urbanization and stream quality impairment 1. JAWRA Journal of the American Water Resources Association, 15(4), pp.948-963.

Lee, S.W., Hwang, S.J., Lee, S.B., Hwang, H.S. and Sung, H.C., 2009. Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics. Landscape and Urban Planning, 92(2), pp.80-89.

Lee, A.H. and Nikraz, H., 2015. BOD: COD ratio as an indicator for river pollution. International Proceedings of Chemical, Biological and Environmental Engineering, 88(15), pp.89-94.

Leopold, L.B., 1968. Hydrology for urban land planning: A guidebook on the hydrologic effects of urban land use (Vol. 554). US Department of the Interior, Geological Survey.

Li, S., Gu, S., Liu, W., Han, H. and Zhang, Q., 2008. Water quality in relation to land use and land cover in the upper Han River Basin, China. Catena, 75(2), pp.216-222.

Liang, Z., Siegert, M., Fang, W., Sun, Y., Jiang, F., Lu, H., Chen, G.H. and Wang, S., 2018. Blackening and odorization of urban rivers: a bio-geochemical process. FEMS microbiology ecology, 94(3), p.fix180.

Mander, Ü., Kuusemets, V., Lõhmus, K. and Mauring, T., 1997. Efficiency and dimensioning of riparian buffer zones in agricultural catchments. Ecological engineering, 8(4), pp.299-324.

Mazhindu, E., Gumbo, T. and Gondo, T., 2012. Waste Management Threats to Human Health and Urban Aquatic Habitats–A Case Study of Addis Ababa, Ethiopia. Rebellon, LFM (Ed.), pp.21-54.

Moore, R.D., Richards, G. and Story, A., 2008. Electrical conductivity as an indicator of water chemistry and hydrologic process. Streamline watershed management Bulletin, 11(2), pp.25-29.

Patricia Gober, Kelli L. Larson, Ray Quay, Colin Polsky, Heejun Chang & Vivek Shandas (2013) Why Land Planners and Water Managers Don't Talk to One Another and Why They Should! Society & Natural Resources: An International Journal, 26:3, 356-364, DOI: 10.1080/08941920.2012.713448

Paul, M.J. and Meyer, J.L., 2001. Streams in the urban landscape. Annual review of Ecology and Systematics, 32(1), pp.333-365.

Pieterse, N.M., Bleuten, W. and Jørgensen, S.E., 2003. Contribution of point sources and diffuse sources to nitrogen and phosphorus loads in lowland river tributaries. Journal of Hydrology, 271(1-4), pp.213-225.

Prominski, M., Stokman, A., Stimberg, D., Voermanek, H., Zeller, S. and Bajc, K., 2017. River. Space. Design: Planning Strategies, Methods and Projects for Urban Rivers. Birkhäuser.

Seyoum Leta, Andualem Mekonen, Eshetu Alemu, Tadesse Alemu, Zerihum Abate, Eyob Yilma, Gulelat Teshome, Hanna Habtemariam, Challa Ragassa and Mesfin Sahle, Teshome Soromessa, Ahmed Hussen,Walelegn Dessalign,Debella Birru and Dejene Tsegaye (2017). Pollution and Sanitation Study for Addis Ababa Rivers and Riversides Development Plan Project, Center for Environmental Science, Addis Ababa University, Addis Ababa.

Sliva, L. and Williams, D.D., 2001. Buffer zone versus whole catchment approaches to studying land use impact on river water quality. Water research, 35(14), pp.3462-3472.

Spänhoff, B., Dimmer, R., Friese, H., Harnapp, S., Herbst, F., Jenemann, K., Mickel, A., Rohde, S., Schönherr, M., Ziegler, K. and Kuhn, K., 2012. Ecological status of rivers and streams in Saxony (Germany) according to the water framework directive and prospects of improvement. Water, 4(4), pp.887-904.

Teurlincx, S., Kuiper, J.J., Hoevenaar, E.C., Lurling, M., Brederveld, R.J., Veraart, A.J., Janssen, A.B., Mooij, W.M. and de Senerpont Domis, L.N., 2019. Towards restoring urban waters: understanding the main pressures. Current Opinion in Environmental Sustainability, 36, pp.49-58.Ward, P., Pauw, W., van Buuren, M. and Marfai, M. (2012). Governance of flood risk management in a time of climate change: the cases of Jakarta and Rotterdam. Environmental Politics, 22(3), pp.518-536.

White, M.D. and Greer, K.A., 2006. The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Penasquitos Creek, California. Landscape and urban Planning, 74(2), pp.125-138.

Weldegebriel, Y., Chandravanshi, B.S. and Wondimu, T., 2012. Concentration levels of metals in vegetables grown in soils irrigated with river water in Addis Ababa, Ethiopia. Ecotoxicology and Environmental Safety, 77, pp.57-63.

Worku Y, Giweta M (2018) Can We Imagine Pollution Free Rivers around Addis Ababa city, Ethiopia? What were the Wrong-Doings? What Action Should be Taken to Correct Them? J Pollut Eff Cont 6: 228. doi: 10.4172/2375-4397.1000228

World Health Organization, 2004. Guidelines for drinking-water quality (Vol. 1). World Health Organization.

Xu, G., Ren, X., Yang, Z., Long, H. and Xiao, J., 2019. Influence of Landscape Structures on Water Quality at Multiple Temporal and Spatial Scales: A Case Study of Wujiang River Watershed in Guizhou. Water, 11(1), p.159.

Yabe, J., Ishizuka, M. and Umemura, T., 2010. Current levels of heavy metal pollution in Africa. Journal of Veterinary Medical Science, 72(10), pp.1257-1263.

Yohannes, H. and Elias, E., 2017. Contamination of rivers and water reservoirs in and around Addis Ababa City and actions to combat It. Environ. Pollut. Climate Change, pp.1-12.

Tables

Table 1 Land use types of the three sub-watersheds

(Source: Digitized from aerial photograph of 2016).

Sub-Watersheds	Built-up or settlement		Cultivated land		Forest land		Bare land		Total	
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%
Denkaka (ADSW)	474.40	19.17	1110.90	44.90	844.80	34.14	44.10	1.78	2474.20	**100**
Little-Kebena (FDSW)	356.80	21.50	282.10	17.00	1010.10	60.87	10.40	0.63	1659.40	**100**
Ginfle (UDSW)	350	90.44	29	7.49	6	1.55	2	0.52	387	**100**
Lower part of Kebena	524.97	72.21	7.84	1.07	192.87	26.53	1.31	0.18	727	**100**
Total area of Kebena	1706.17	32.51	1429.84	27.25	2053.77	39.14	57.81	1.10	5247.6	**100**

Table 2 Mean values of seasonal water quality indicators in the Kebena watershed

Variable	Season		t -Value	P-Value
	Wet	Dry		
PH	6.23	7.87	-14.609	0.000**
Total Dissolved Solid (TDS) mg/l	255.00	900.00	-35.514	0.000**
Total Suspended Solid (TSS) mg/l	101.38	156.00	-2.242	0.030*
Electrical Conductivity (EC) µs/cm	444.50	1801.19	-35.362	0.000**
Ammonia, mg/l	6.63	84.29	-12.218	0.000**
Total Nitrogen (TN), mg/l	6.30	75.86	-10.758	0.000**
Total Phosphorus (TP), mg/l	.55	8.24	-6.987	0.000**
Chloride, mg/l	51.92	87.71	-10.443	0.000**
Chemical Oxygen Demand, (COD), mg/l	63.00	99.73	-3.354	0.001**
Biological Oxygen Demand, (BOD), mg/l	25.28	64.63	-3.356	0.002**
** and * Significant at 1% and 5% significance level respectively.				

Table 3 Mean values of water quality indicators in the sub-watersheds in different seasons

Variable	Forest dominated (Little-Kebena)		Agriculture dominated (Denkaka)		Urban dominated (Ginfle)		Entire Kebena watershed		F Value (Dry)	Sig. (Dry)	F Value (Wet)	Sig. (Wet)
	dry	wet	dry	wet	dry	wet	dry	wet				
PH	8	5.92	8.08	5.64	7.65	6.64	7.77	6.71	6.98	0.001**	12.48	0.000**
TDS mg/l	885	170	917	279	921	362	877.00	209.00	.83	.486	35.87	0.000**
TSS mg/l	56	150	36	81	339	72.5	193.00	102.00	25.56	0.000**	22.77	0.000**
EC	1766	339	1831.6	235.2	1853	784.7	1754.15	419.10	2.46	.079	122.51	0.000**
Ammonia, mg/l	49.5	2.51	65	0.75	138.1	18.25	84.55	5.00	32.94	0.000**	648.15	0.000**
T-N, mg/l	42.45	4.1	54	3	129	10	78.00	8.10	25.77	0.000**	47.05	0.000**
T- P, mg/l	4.3	0.12	4.4	0.37	16.09	1.55	8.16	0.15	11.58	0.000**	46.65	0.000**
Chloride, mg/l	94.22	44.25	102.83	36.61	79.2	78.8	74.59	48.00	35.66	0.000**	110.34	0.000**
COD, mg/l	46	39	34	55	157	114	161.90	44.00	353.01	0.000**	165.74	0.000**
BOD, mg/l	40.2	10.2	23	11.9	12.1	63	183.20	16.00	754.83	0.000**	287.12	0.000**
** and * Significant at1% and 5% significance level respectively												

Table 4 Results of multiple regression of the effect of land use, within the three sub watersheds and Kebena watershed, on water quality over two seasons (+ represents positive while - represents a negative relationship)

Wet	FDSW (Little-Kebena)	ADSW (Denkaka)	(UDSW) Ginfle	Kebena	R^2
PH	-0.81**	-1.09**	-0.10	-0.02	0.54
TDS	135.37**	244.37**	327.37**	174.37**	0.89
TSS	109.3**	40.3**	31.8**	61.3**	0.77
EC	270.73**	166.93**	716.43**	350.83**	0.94
Ammonia	1.26**	-0.50	17.0**	3.75**	0.98
TN	-10.3**	-11.4**	-4.4**	-6.3**	0.86
TP	-0.43**	-0.18	1.0**	-0.40**	0.76
Chloride	21.83**	14.19**	56.38**	25.58**	0.91
COD	24.9**	40.9**	99.9**	29.9**	0.95
BOD	7.65**	9.35**	60.45**	13.4**	0.97
Dry					
PH	0.59**	0.67**	0.23*	0.36**	0.57
TDS	754.24**	786.24**	790.24**	746.24**	0.95
TSS	-26.85	-46.85	256.15**	110.15**	0.68
EC	1494.84**	1560.44**	1581.84**	1482.99**	0.98
Ammonia	38.95**	54.45**	127.55**	74.0**	0.84
TN	33.15**	44.7**	119.7**	68.7**	0.79
TP	-4.64	-4.54	7.16**	-0.78	0.42
Chloride	83.18**	91.79**	68.16**	63.55**	0.97
COD	33.5**	21.5**	144.5**	149.4**	0.98
BOD	29.28**	12.08**	1.18	172.28**	0.99

*The reference water quality indicator is Forest source point ** and * are significant at 1% and 5% levels, respectively.*

Figures

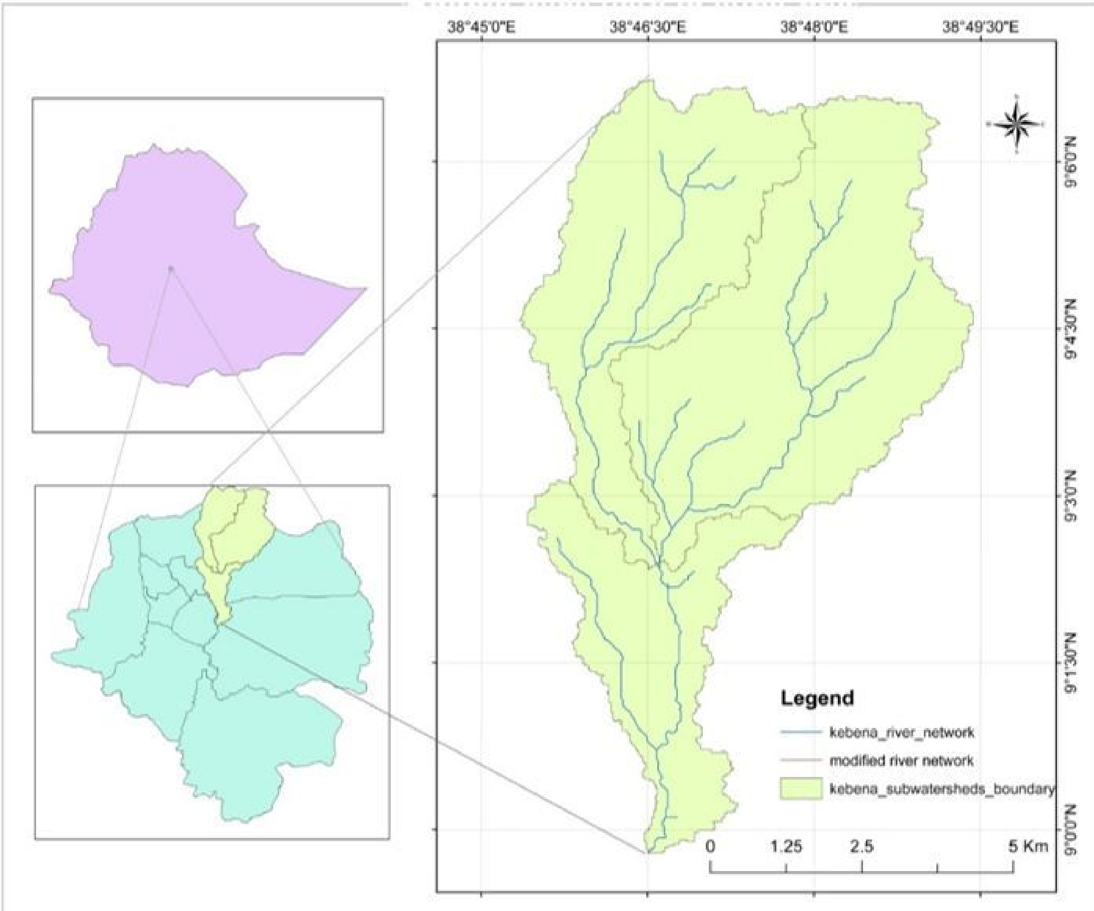

Figure 1

Location Map of the Kebena watershed in Addis Ababa

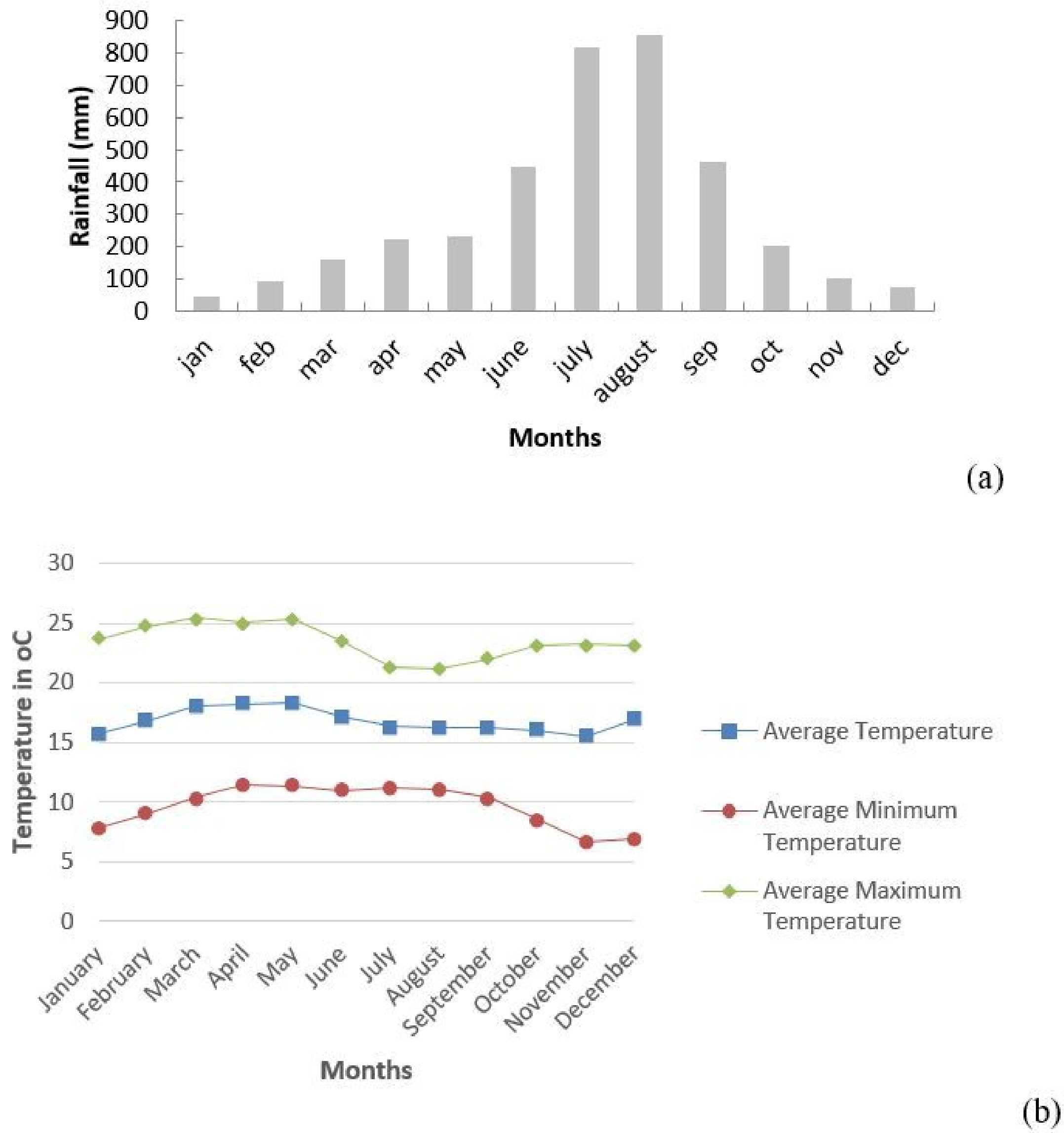

Figure 2

Mean annual rainfall (a) and temperature distribution (b) in the city of Addis Ababa (averaged from 30 years data record)

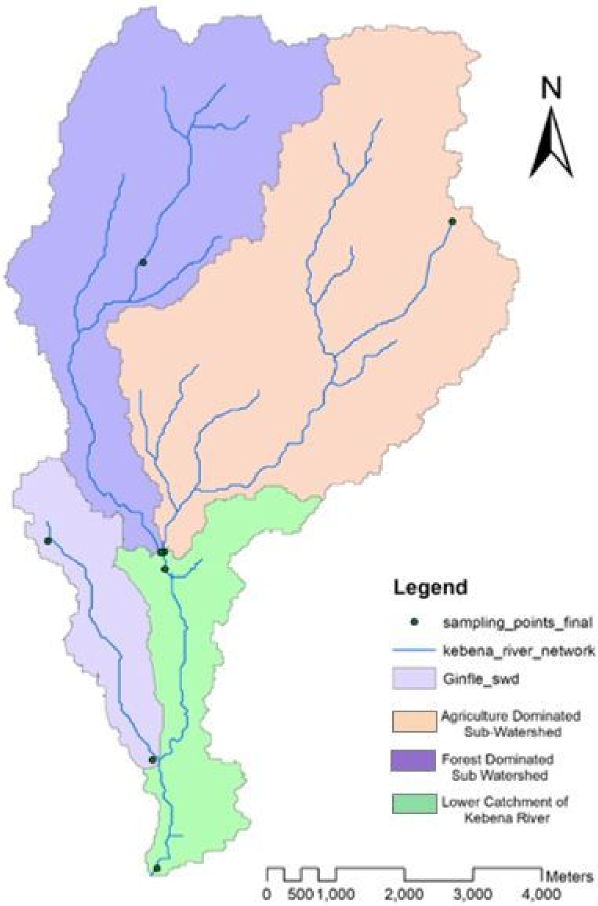

Figure 3

Map of the Kebena Watershed and its sub-watersheds

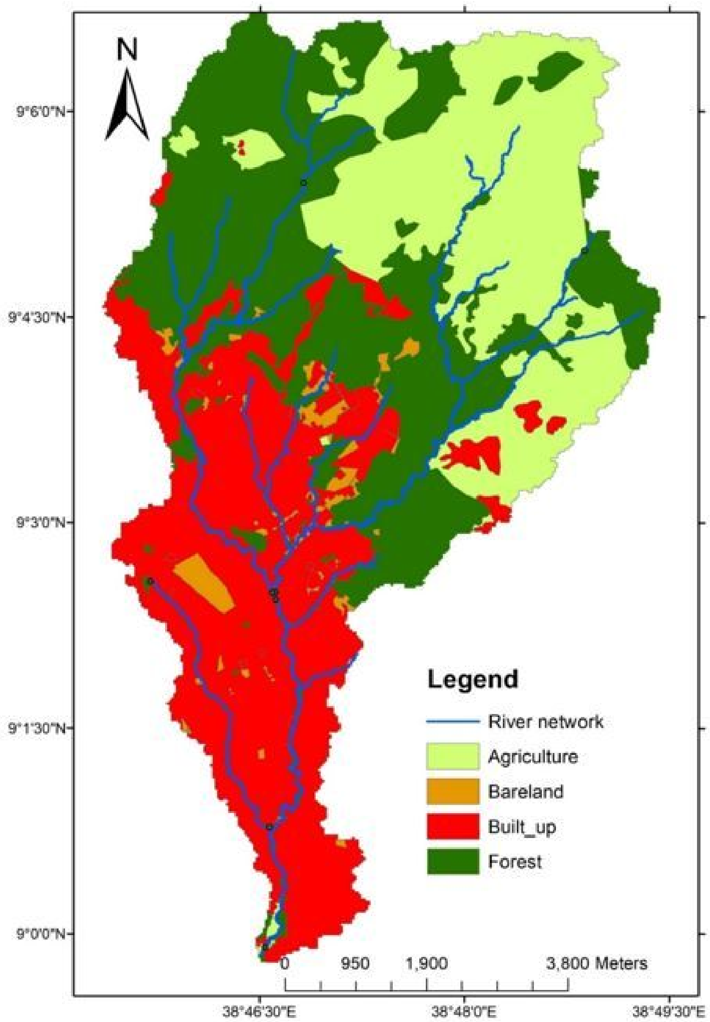

Figure 4

Map of Land Use types of the catchments within the Kebena River Watershed