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Impacts of Water Pollution of River Njoro in Eastern Mau Forest Ecosystem on Agriculture, Land and Aquatic Environments, Kenya

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Abstract

One major problem that humanity has been confronting recently is water quality. Just 2.5 percent of the water resources on Earth are freshwater resources. Water is an indispensable resource for all living things, and it is a vital value. Pollution of limited freshwater resources causes further pressure on freshwater resources. Humans play a major role in the waste and pollution of this essential natural resource. This research project focused on the impacts of water pollution and its effects on agriculture, land and aquatic systems, a case study which was conducted in River Njoro, in Nakuru County. With the aid of questioners for information acquisition, the study determined different pollutants and their impact on agriculture. Results indicated that there is a dire need for conservation efforts in the area. Humanity should receive education awareness-capacity building regarding water contamination in order to mitigate the issues to some extent. By doing so, the world we live in becomes a better place for all.

Keywords

Water Pollution, Remote Sensing, Ecosystems, Aquatic Environment, Water Quality

1. Introduction

The assessment of water pollution in River Njoro, originating from the Eastern Mau Forest Complex and flowing into Lake Nakuru, holds significant importance due to its potential impacts on agriculture, land, and aquatic ecosystems. This study aims to comprehensively analyze the extent of pollution along the river's course and evaluate its consequences on various aspects of the environment.

Water pollution occurs chemically or biologically, and then the water quality becomes poor and polluted. This water has negative impact on living aquatic organisms and plants. And its effects not only impact people, but they also can kill other aquatic organisms. The unplanned urbanization, agrochemicals, domestic waste, sewage system, from brick field has affected all living organism in the river water and destroyed the food chain in the river (Wikipedia, 2019). Preceding studies have applied a variety of tools and techniques, ranging from conventional to modern, for characterization of the water quality worldwide. Recently, geographic information system (GIS) technology and Remote Sensing has been successfully integrated with the advanced statistical methods, providing improved interpretation capabilities for the assessment of the water quality over different spatial scales. Assessing water pollution using Geographic Information Systems (GIS) and Remote Sensing methods can provide valuable insights into the extent, sources and spatial distribution of pollutants in water bodies. Integrating remote sensing data with GIS allows for spatial analysis and mapping of water quality parameters (Chrisphine et al., 2016) who focused on the catchment area of the river Njoro. GIS provides tools to overlay and visualize water quality data, analyze trends, identify hotspots of pollution, and assess changes over time. To assess water pollution, it's essential to identify the relevant water quality parameters to be measured. Common parameters include: Total Phosphorous (TP), Total Suspended Solids (TSS), Total Nitrogen (TN), Chlorophyll, Turbidity and Biological Oxygen Demand (BOD).

GIS technology has been widely employed in water quality studies due to its ability to integrate diverse spatial datasets. Researches have demonstrated the utility of GIS in mapping Water quality to determine the chemical, physical and biological characteristics of water bodies and identify the source of any possible pollution or contamination which might cause degradation of the water quality (Omondi et al., 2023). Chemical characteristic being the pH, dissolved oxygen demand, nutrients such as nitrogen and phosphorous, organic and inorganic compounds. Biological characteristics being bacteria, algae and physical characteristics being temperature, suspended solids, dissolved solids, salinity etc. land use patterns and identifying potential pollution sources, laying the foundation for subsequent studies to focus on specific regions for targeted interventions. The research consolidated water quality data for utilization in present information, from the statistical analysis the study revealed few differences among agencies for nitrogen compounds and total Kjeldahl nitrogen (KTN). Consequently, the research found out that data from different sources and locations of the stream was useful in characterizing difference in analytical results of chemically similar nitrogen parameters. Remote Sensing, particularly satellite imagery, provides a synoptic view of large areas, allowing for the assessment of changes in land cover and water bodies. The work of exemplifies the use of remote sensing coupled with GIS to monitor water quality parameters using reflected and/or emitted electromagnetic radiation from water surface. Such changes could be monitored and detected by remote sensing using different spectral reflectance. The study explores the potentiality of using remote sensing and GIS techniques to detect most vulnerable areas to water pollution.

The synergy between GIS and Remote Sensing enhances the accuracy and comprehensiveness of water quality assessments (Griffith, 2002; Mustafa et al., 2017) demonstrates a study undertaken by analyzing data from satellite image (Landsat-8 OLI) and geographical information system (GIS) to find the relationship between water parameters and water indices of spectral images by developing a model for the physical and chemical water parameters. The water parameters used in this study included: acidity (PH), Total Dissolved Solids (T. D. S), Alkalinity (ALK), Electrical Conductivity (E. C), Calcium (Ca), Chloride (CL), Sodium (Na), Sulfate (SO_4), Potassium (k), Total suspended solid (T. S. S), Total Hardness (TH). Where the samples were taken to seventeen stations with two seasons and at the same time took a satellite image. GIS techniques were used in the beginning to project the coordinates of seventeen stations along the stream in Landsat-8 satellite image for extract data. Then, these data are treated in SPSS software for purpose finding correlation and regression equations. Positive strong correlations between the reflectance of the satellite image and the water parameters helped to build the regression models. These models could be used to predict these six water parameters (PH, E. C, CL, SO_4, Na and K) at any point along the stream from the satellite image directly.

A study by Maliki et al. (2020) shows how remote sensing was used to estimate the concentration of total dissolved solids (TDS) in the river using Landsat 8 images to help monitor water quality, help in decision making and provide solution for water resources planning. After processing of atmospheric correction and inserted remote sensing indices, the reflectance of water extracted from satellite images was used to express the spectral characteristics of different TDS concentrations. Correlation and regression were used to obtain accurate models for detecting the salinity depending on the spectral reflectance of Landsat 8 operational land image OLI. The results presented Pearson correlation (r) value of 0.70, 0.97, and 0.71, and correlation coefficient (R^2) of 0.56, 0.94, and 0.85 between field data with spectral data of salinity index 2 (SI-2) derived from the green and blue bands of Landsat images.

Griffith (2002) illustrates the need to address water-quality analyses related to the geographically widespread nature of non-point source pollution problems, to analyze mid- to large-sized watersheds across wide regions in an efficient manner using remote sensing technique has been the impetus behind a landscape approach to water quality studies. The approach involves examining the entire catchment of streams using Aerial photography to make analysis of landscape classification and create DEMs for hydrologic modeling.

Studies by Chabuk et al. (2020) focus on evaluating the water quality of Mahananda river and to analyze the suitability for drinking, agricultural and industrial uses utilized remote sensing. Samples from sampling stations were collected in pre-monsoon and post-monsoon seasons and water quality index (WQI) agriculture and industry-related indices were computed using the different image band reflectance (Jonnalagadda & Mhere, 2001; Shil et al., 2019).

Understanding the implications of water pollution on human health is a critical aspect of water quality assessments. Mustafa et al. (2017) explored the use of GIS to spatially analyze water contamination problem in third world countries using water quality index method and GIS software. Twelve parameters (Ca, Mg, Na, K, Cl, SO_4, HCO_3, TH, TDS, BOD_5, NO_3, and EC) were taken from sample stations along the river. The weighted arithmetic method was applied to compute the water quality index (WQI). The interpolation method (IDW) was applied in ArcGIS 10.5 to produce the prediction maps for 12 parameters.

The main reason for this study is to assess the spatial extent, temporal and impact of water pollution on ecosystems and biodiversity. The study is essential for understanding the multifaceted impacts of poor water quality on the environment, human health, and the economy. The research will help in providing recommendations for effective water management strategies hence promoting the development of informed policies, promoting sustainable practices hence ensuring the well-being of both ecosystems and communities at large.

2. Literature Review

2.1. International Studies in River Pollution

According to Mustafa et al. (2017) who conducted a study on evaluating river water quality index while utilizing remote sensing and AI models measured 13 water quality parameters including turbidity, dissolved Oxygen, Potassium, Nitrate. The parameters were measured between two dates at a site in different dates.

Chabuk et al. (2020) conducted the quality of water on Tigris river using GIS and remote sensing where they tested 14 different locations measuring TDS, pH, Turbidity, chlorophyl A, Blue-green algae and dissolved oxygen were the testing parameters. They employed the use of spectral bands and indices in LASSO model where they found that the water quality Index (WQI) was low indicating poor water quality along the stream (Jonnalagadda & Mhere, 2001).

Othe researchers have conducted a review on applicability of remote sensing and GIS in river relation studies. The authors conducted a review of sixty-nine research papers. Based on the scrutiny the authors found out that remote sensing data, popular ones being Landsat, sentinel and digital Elevation Model datasets, with the extracted information being indices for main parameter for understanding the rivers.

Adilakshmi & Venkasetan (2024) conducted a study on river Noyyal to understand the water quality nature. This research also utilized Lasso model for predicting the water quality index noting that the model provided a cost-effective method of monitoring the water quality in the river. The study also showed the importance of WQI in indicating the quality of water during the monitoring period showing the magnitude of pollution.

2.2. Effects of Water Pollution on Agriculture, Land and Aquatic Life

Water pollution has not only negative impacts on human but also agriculture, land and aquatic life below are some of the effects:

2.2.1. Effect of Water Pollution (Detergents Deposition) on Plants

Water bodies are contaminated by industrial and household detergents, which have detrimental impacts on plants. Water becomes enriched in phosphates due to the high phosphate content of detergents. Through surface absorption or roots, phosphates enter plants and cause a variety of negative effects, including denaturation of proteins, destruction of chlorophyll and cell membranes, elongation of roots, carbon dioxide fixation, photosynthesis, cation uptake, pollen germination, and growth of pollen tubes (Singh & Gupta, 2017).

2.2.2. Effects of Water Pollution (Agricultural Chemicals) on Plants

Overuse of pesticides, herbicides, fertilizers, and other chemicals on crops results in runoff that carries the chemicals into the soil and eventually reaches water bodies. Fertilizer chemicals cause eutrophication by nutrient enrichment. Water becomes acidic due to the acidic nature of ammonium from fertilizers. In a similar vein, insecticides, herbicides, and pesticides similarly alter the pH of water bodies. The decrease in photosynthetic rate is these drugs' most frequent side effect. Some could impede or decouple oxidative phosphorylation. Due to their limited solubility in water, these compounds have considerable capacities for absorption and bioaccumulation in macrophytes plants (Singh & Gupta, 2017; Craswell, 2021; Watelet and Johnson, 1999).

2.3. Effects of Water Pollution on Land (Soils)

Globally, an estimated 20 million hectares of arable land are irrigated with water that has been partially or completely treated by leftover amounts of household liquids. Because of the presence of heavy metals, which are deemed hazardous due to their potential toxicity and environmental persistence, there are dangers to ecosystems and public health. Since they fall into two groups, heavy metals and trace elements in the soil system are particularly interesting topics. In contrast, cadmium (Cd), lead (Pb), chromium (Cr^{6+}), nickel (Ni), mercury (Hg), and arsenic (As) are not only not essential to plants but also toxic even at very low concentrations. Metals like copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), and molybdenum (Mo) have been identified as essential micronutrients for plant growth. Heavy metal buildup in agricultural soils has the potential to have a detrimental impact on human health by moving up the food chain from soil to plants to people.

2.4. Effects of Water Pollution (Organic Effluents) on Water Quality

Some research on River Njoro has shown that there is a clear growing human activity that results in the discharge of organic wastewater which has a significant negative influence on the Njoro River. Organic waste discharges have led to a decline in water quality. The diversity and composition of macroinvertebrate species have changed as a result of changes in the physico-chemical water quality parameters. Thus, along the lower research sites, pollution-tolerant Polypedilum sp. became dominant. These findings unequivocally demonstrate how rising human activity levels in the Njoro River watershed, in particular, affect the quality of the water. The study's findings show that a damaged aquatic ecosystem will alter the community structure of aquatic fauna and impede crucial ecological functions, such as the organism's innate ability to purify itself. Therefore, it is imperative to preserve the ecological integrity of the Njoro River water resource by limiting human activity, protecting the river's channel and basin, and raising public knowledge of environmental integrity through education. Therefore, all parties involved should prioritize developing a management plan and putting rules in place to reduce and regulate pollution in the Njoro River.

2.5. Impact of Polluted Water on Aquatic System

Polluted water has detrimental effect on the aquatic life as illustrated by Malik et al. (2024).

2.5.1. Impact of Polluted Water on Fish

A high concentration of suspended water contaminants can interrupt the normal behavior of fish populaces. Many fish species, such perch and brown trout, are highly sensitive to elevated suspended solids and exhibit severe avoidance behavior (Malik et al., 2024). These species rely on sight to quickly capture their meal. When a fish species lives in an environment with murky water, suspended materials may damage or block the gill aperture, decreasing the fish's susceptibility to certain diseases and parasites. Fish species may also ingest these suspended particles, which exposes them to possible poisons or pathogens on the sediment and can cause disease.

2.5.2. Impact of Polluted Water on Algae and Macrophytes

Whether they are submerged, floating, or emergent, macrophytes are aquatic plant species that grow in water. Because they react swiftly to changes in the pace and variety of several environmental factors, including as water flow, alkalinity, substrate, shade, and nutrient concentrations, macrophytes are considered bioindicators. The total amount of suspended sediment has a negative effect on aquatic macrophytes and algae by reducing the amount of light that reaches the water column, which in turn reduces the frequency of photosynthesis. Fast flowing rates frequently carry large amounts of suspended particles, which also brush aquatic macrophytes and algae away from bed substrates, damaging their photosynthetic structures. The submerged flora may be choked by the sedimentation process, drastically slowing down photosynthesis. While certain plants thrive in water with high DO and little dissolved oxygen, others do well in water with more nutrients. Because of this, aquatic macrophytes might be ranked and scored based on how well they adapted to different chemical and physical environments. Aside from that, macrophytes are robustly predisposed by soil type and geology, and they can withstand unpredictable pollution. Furthermore, the organization of macrophyte communities is often determined by a number of interrelated factors, which can make it challenging to attribute a species' presence or absence to a particular contaminant in any body of water, macrophytes are an essential bio indicator of ongoing pollution issues (Malik et al., 2024).

3. Materials and Methods

3.1. Study Area

Our study area is along River Njoro/Ndarugu River, a third order stream in Kenya, Nakuru county. River Njoro watershed is located Kenya's southwestern Rift Valley at 0˚30' South, 35˚20' East. The river is approximately 50 km in length with an estimated 270 km^2 contributing source area, originating in the Eastern Mau Escarpment at approximately 3000 m. River Njoro winds through forested and agricultural lands before serving several urban settlements and finally emptying in Lake Nakuru, a shallow salty lake. Figure 1 below shows the study area.

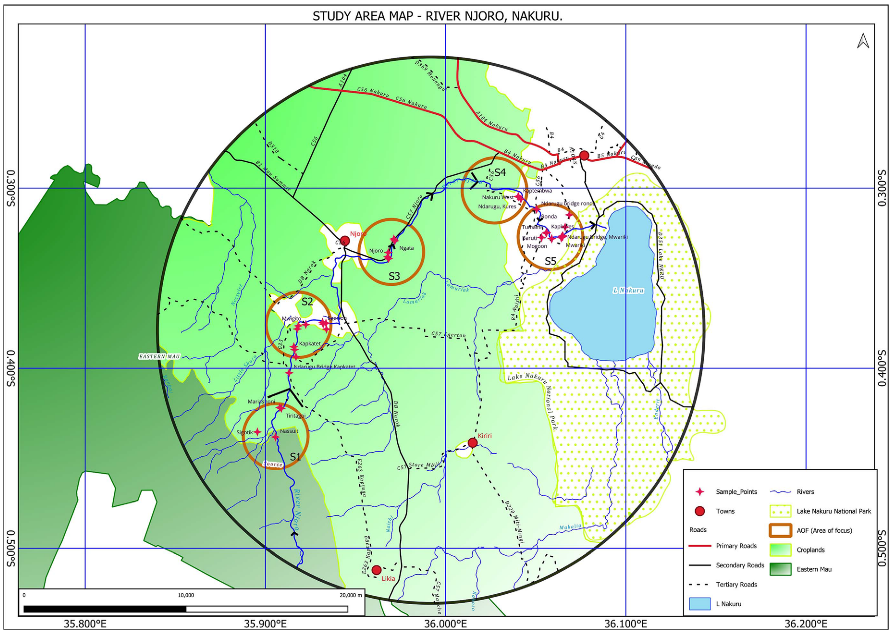

Figure 1. Study area map.

The main economic activities in the area are agriculture-based industries including vegetable and milk processing, large-scale wheat, maize, barley farming and green house flower farming.

3.2. Data

Table 1. A list of the data utilized, their resolution, sources and purpose of use.

Data	Source	Spatial Resolution (m)	Purpose
Landsat images	Earth Explorer USGS	30 m	To generate LULC maps for the 3 epochs.
Landsat images	Earth Explorer USGS	30 m	To compute NDNI maps for the 3 epochs.

Continued

Landsat images	Earth Explorer USGS	30 m	To compute NDPI maps for the 3 epochs.
Landsat images	Earth Explorer USGS	30 m	To compute NDWI maps for the 3 epochs.
Landsat images	Earth Explorer USGS	30 m	To compute NDMI maps for the 3 epochs.

For the assessment of water pollution using GIS and Remote sensing methods we incorporated a number of data. Data were acquired for the years 2000, 2010 and 2020. Nitrogen, Phosphorous and Biological Oxygen Demand were calculated from satellite images from different spectral reflectance using the raster calculator tool. Satellite images were obtained from the US Geological Survey (USGS) Earth Explorer Landsat 7 for 2000 processes, Landsat for 2010 processes and Landsat 8 for 2020 data processing. Land Use Land Cover maps for the corresponding years were generated using satellite images obtained from USGS. Table 1 above shows the data used.

The study area was divided into five zones;

1) near the source, Eastern Mau Forest.

2) around Egerton dams and Njoro caves.

3) around Njoro near Kenyatta stage.

4) around Kaptembwa.

5) around Nakuru sewage treatment plant.

Calculate water quality indices that are correlated with Total Nitrogen (TN), Total Phosphorous (TP) and Biological Oxygen Demand (BOD) using Landsat imagery.

3.3. Methodology

The analysis of the data was carried out in ENVI, ArcGIS software and quantifying the output using Microsoft excel. Several steps in image processing and analysis were carried out in order to obtain the final results. Processing and integration were done using ArcMap software and ENVI tools. Integrating remote sensing data with GIS allows spatial analysis and mapping of water quality parameters. GIS provides tools to overlay and visualize water quality data, analyze trends, identify hotspots of pollution, and assess changes over time (Chabuk et al., 2020). Land use land cover maps were generated for the three epochs (2000, 2010, 2020) to see the influence or impacts it has to the water quality parameters. The maps were generated using supervised classification, a process where you select representative samples for each land cover class in the satellite image to identify land cover classes in the entire image. To assess water pollution, it's essential to identify the relevant water quality parameters to be measured. In this study, we focused on the Common parameters; Total Phosphorous (TP), Total Nitrogen (TN), and Biological Oxygen Demand (BOD).

The methodology (Figure 2) employs the utilization of remotely sensed satellite data which undergoes image enhancement for utilization in subsequent image processes. The chosen image for the year 2000, 2010 and 2020 undergoes processing for pollution mapping for the study river with the three indices being utilized for the investigation generated the Nitrogen Differential Nitrogen Index (NDNI), Normalized Difference Phosphorus Index (NDPI), Normalized Difference Water Index (NDWI). An overlay analysis is carried out and finally a validation and correlation carried out the corresponding statistics for the degree of impact and are coverage are also generated for each year.

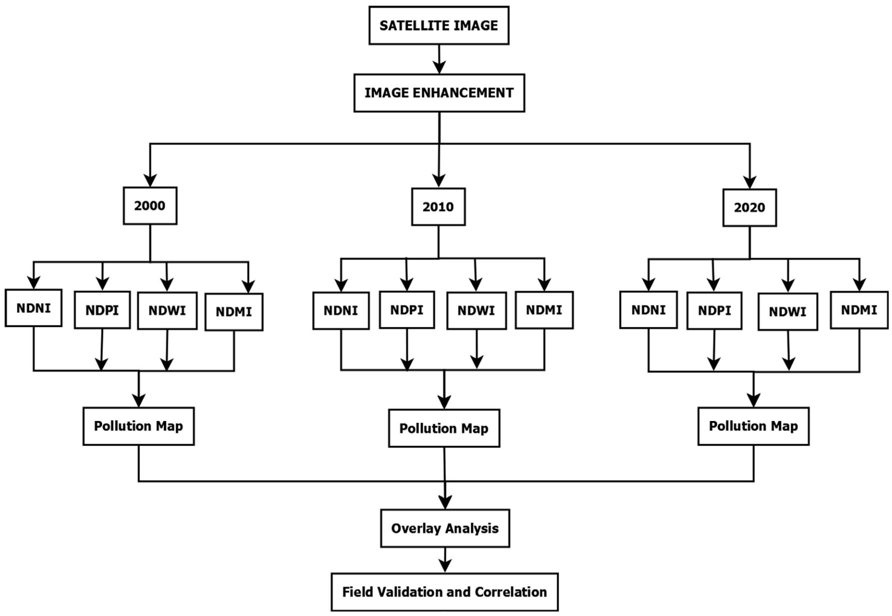

Figure 2. Workflow methodology employed in the research execution.

The technology (Figure 2) utilizes remotely sensed satellite data, which is enhanced for subsequent image treatments. The selected image for the years 2000, 2010, and 2020 is processed to create pollution maps for a study on a river. Three indices are used for the investigation: The Nitrogen Differential Nitrogen Index (NDNI), the Normalized Difference Phosphorus Index (NDPI), and the Normalized Difference Water Index (NDWI). An overlay analysis is conducted, followed by a validation and correlation process. Statistics regarding the degree of impact and coverage are generated for each year.

3.4. Water Quality Indices Analysis

3.4.1. Nitrogen

Nitrogen (N) in the form of nitrate is a common pollutant in surface and ground waters. The source of Nitrate-N is leach down beyond the root zone in agricultural soils and reach the ground and surface waters (Jonnalagadda & Mhere, 2001). Nitrogen Differential Nitrogen Index (NDNI) is helpful in identifying areas affected by stressors such as pollution, disease, or physical damage. It's calculated from the reflectance values of shortwave infrared (SWIR) and red (R) bands;

$$\text{NDNI} = (\text{SWIR Band} - \text{RED Band})/(\text{SWIR Band} + \text{RED Band})$$

2000

$$\text{NDNI} = (\text{Band 5} - \text{Band 3})/(\text{Band 5} + \text{Band 3})$$

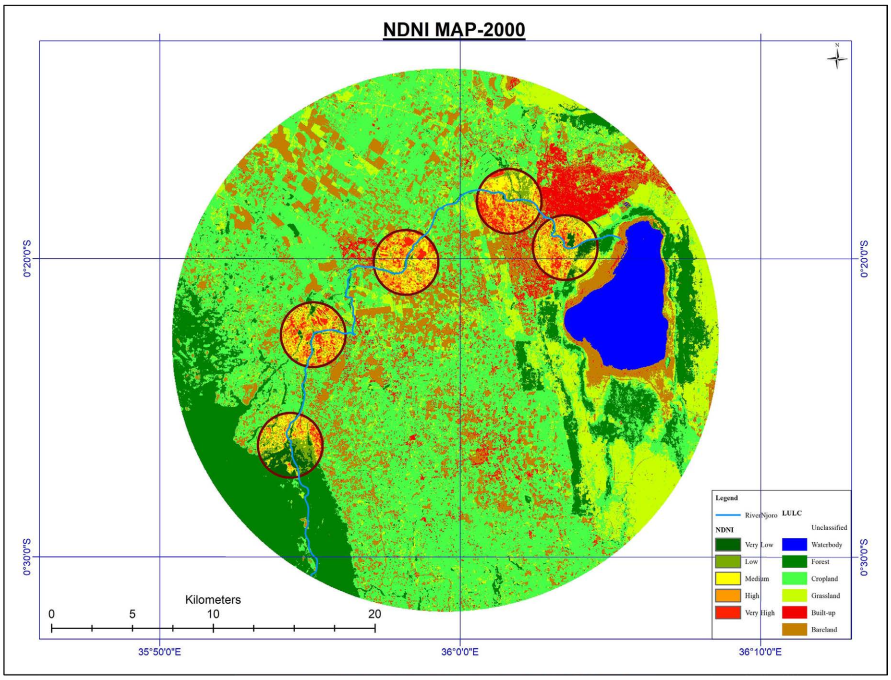

Figure 3. NDNI map 2000.

Table 2. NDNI area distribution for the 6 classes 2000.

Class	Area (m^2)
High	18,767,995
Low	10,020,224
Medium	20,441,768
Very High	7,932,319
Very Low	5,710,554

NDNI for 2000 ranged from very low to very high. The areas with very low NDNI values were majorly observed on the forested areas while very high NDNI values were majorly on the urban areas as shown in Figure 3 and Table 2.

2010

$$\text{NDNI} = (\text{Band 6} - \text{Band 4})/(\text{Band 6} + \text{Band 4})$$

NDNI for 2010 ranged from very low to very high (Figure 4). The areas with very low NDNI values were majorly observed on the forested areas while very high NDNI values were majorly on the urban areas (Table 3). The NDNI values were increasing as compared to 2000 NDNI values.

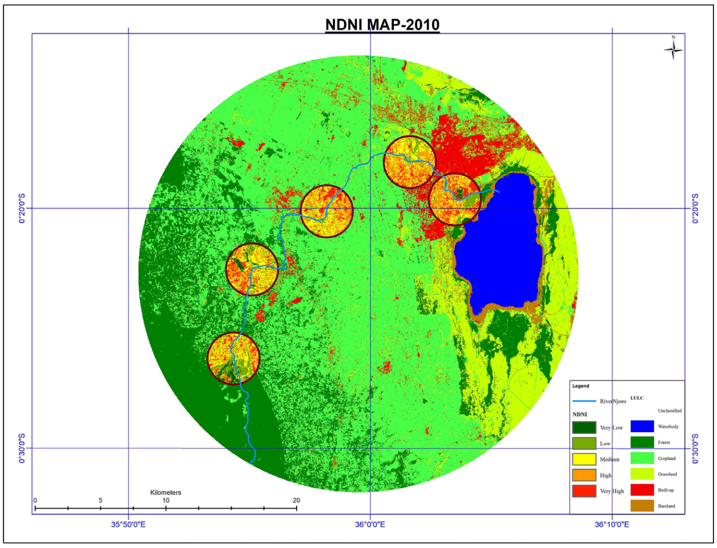

Figure 4. NDNI map 2010.

Table 3. NDNI area distribution graded from very low to high.

Class	Area (m^2)
High	22,890,351
Low	8,103,047
Medium	20,851,451
Very High	7,725,251
Very Low	3,294,460

2020

$$\text{NDNI} = (\text{Band } 6 - \text{Band } 4)/(\text{Band } 6 + \text{Band } 4)$$

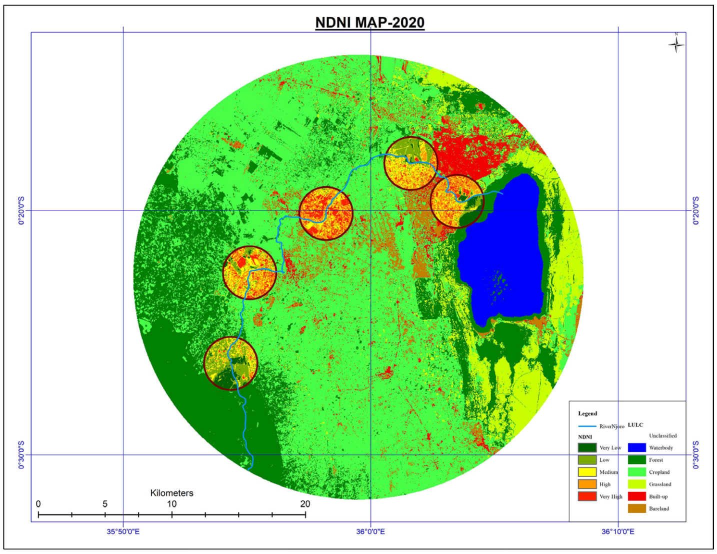

Figure 5. NDNI map 2020.

Table 4. NDNI area distribution graded from very low to high.

Class	Area (m²)
High	25,167,525
Low	5,414,425
Medium	16,655,327
Very High	12,394,545
Very Low	3,220,441

NDNI for 2020 ranged from very low to very high (Figure 5). The areas with very low NDNI values were majorly observed on the forested areas while very high NDNI values were majorly on the urban areas (Table 4). The NDNI values were increasing as compared to 2010 and 2000 NDNI values as shown in Table 5 and graphically in Figure 6 below.

Table 5. NDNI trend analysis 2000, 2010 and 2020.

Trends analysis (years)	2000 (%)	2010 (%)	2020 (%)
Very Low	9	5	5
Low	16	13	9
Medium	32	33	26
High	30	37	40
Very High	13	12	20

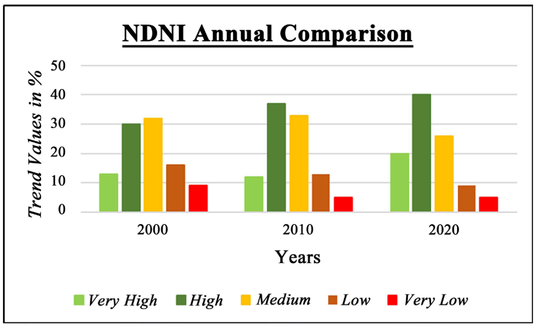

Figure 6. NDNI Annual percentages comparison 2000, 2010, and 2020.

3.4.2. Phosphorous

Available quantity of phosphorous controls the pace at which algae and aquatic plants are produced. In appropriate quantities, phosphorus can be used by vegetation and soil microbes for normal growth. However, in excess quantities, phosphorus can lead to water quality problems such as eutrophication and harmful algal growth. Phosphorus generally occurs in small quantities in the natural environment so even small increases can negatively affect water quality and biological condition. The main sources of phosphorus pollution are sewage effluent (primarily from water industry sewage treatment works) and losses from agricultural land.

Water quality index that can be correlated with Phosphorous is the Normalized Difference Phosphorous Index (NDPI). NDPI is sensitive to changes in Phosphorous content, making it suitable for water quality assessments. NDPI is calculated using Red Band and the Near Infrared band;

$$\text{NDPI} = (\text{RED Band} - \text{NIR Band})/(\text{RED Band} + \text{NIR Band})$$

2000

$$\text{NDPI} = (\text{Band } 3 - \text{Band } 4)/(\text{Band } 3 + \text{Band } 4)$$

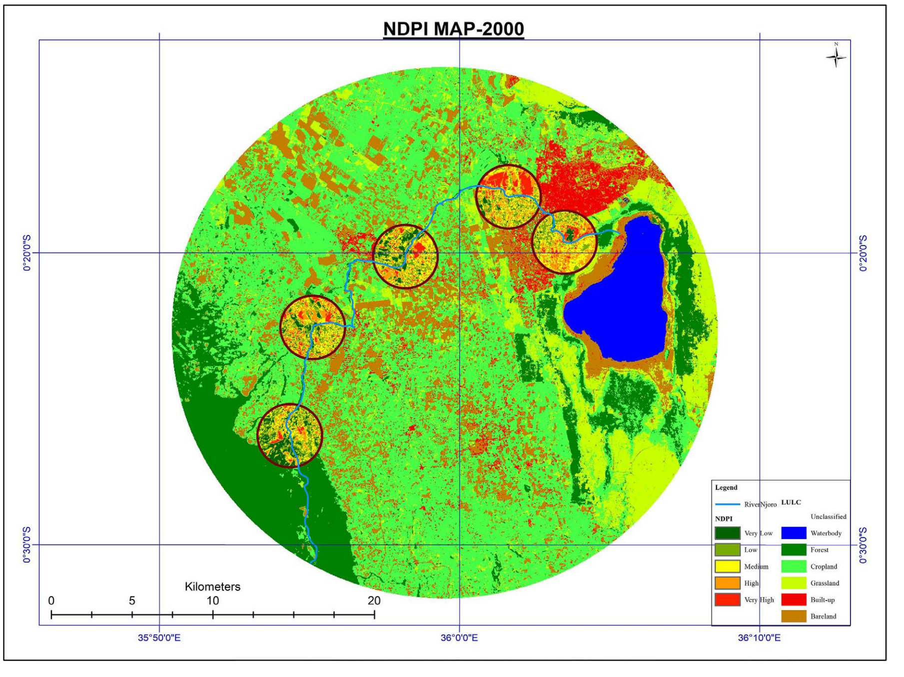

Figure 7. NDPI map 2000.

Table 6. NDPI analysis 2000.

Class	Area (m^2)
High	11,875,399
Low	17,750,390
Medium	18,660,971
Very High	3,750,365
Very Low	10,832,581

NDPI for 2000 ranged from very low to very high as shown in Figure 7 and Table 6. The areas with very low NDPI values were majorly observed on the forested areas while very high NDPI values were majorly on the urban areas.

2010

$$\text{NDPI} = (\text{Band } 4 - \text{Band } 5)/(\text{Band } 4 + \text{Band } 5)$$

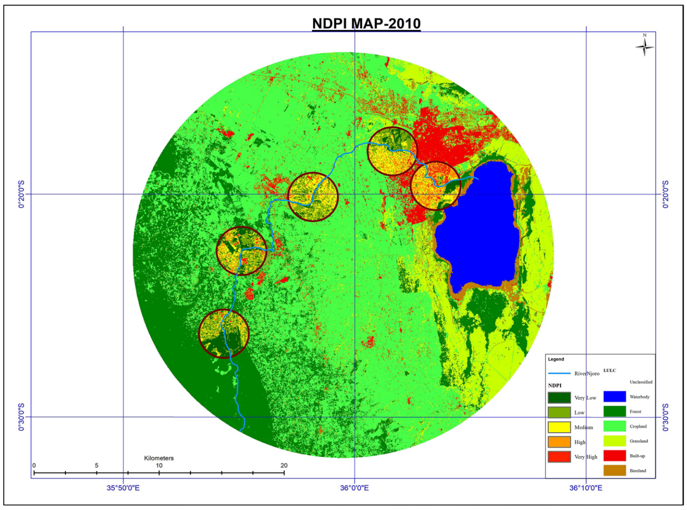

Figure 8. NDPI map 2010.

Table 7. NDPI analysis 2010.

Class	Area (m^2)
High	16,968,818
Low	11,689,447
Medium	21,825,652
Very High	6,634,770
Very Low	5,747,443

NDPI for 2010 ranged from very low to very high (see Figure 8 and Table 7). The areas with very low NDPI values were majorly observed on the forested areas while very high NDPI values were majorly on the urban areas. The NDPI values were increasing as compared to 2000 values.

2020

$$\text{NDPI} = (\text{Band 4} - \text{Band 5})/(\text{Band t4} + \text{Band 5})$$

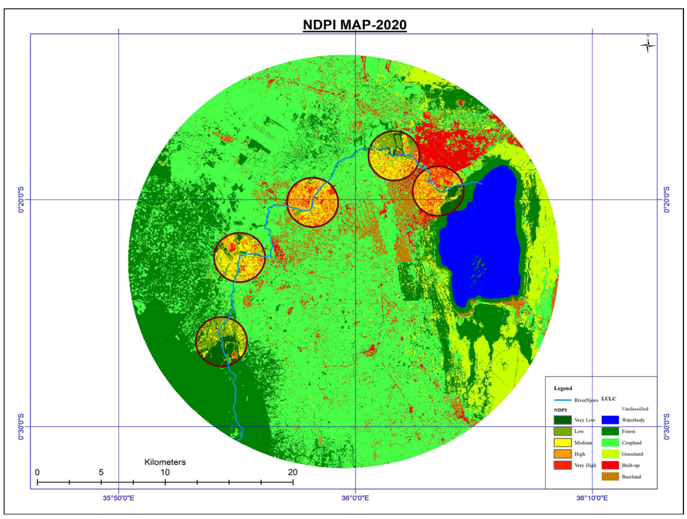

Figure 9. NDPI map 2020.

Table 8. NDPI analysis 2020.

Class	Area (m^2)
High	19,556,755
Low	8,296,861
Medium	23,419,957
Very High	5,377,670
Very Low	6,203,274

NDPI for 2020 ranged from very low to very high (Figure 9 and Table 8). The areas with very low NDPI values were majorly observed on the forested areas while very high NDPI values were majorly on the urban areas. The NDPI values were increasing as compared to 2010 and 2000 NDPI values as shown in Table 9 and Figure 10 below.

Table 9. NDPI trend analysis, 2000, 2010, and 2020.

	2000 (%)	2010 (%)	2020 (%)
Very Low	17	9	10
Low	28	19	13
Medium	30	35	37
High	19	27	31
Very High	17	10	9

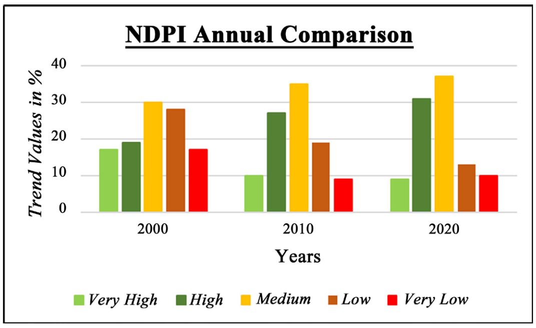

Figure 10. NDPI annual percentages comparison 2000, 2010, and 2020.

3.4.3. Biological Oxygen Demand

Biological oxygen demand is the measure of the amount of oxygen required to remove waste organic matter from water in the process of decomposition by aerobic bacteria. The presence of high BOD may indicate contamination or increases in particulate and dissolved organic carbon from non-human and animal sources that can restrict water use and development, necessitate expensive treatment and impair ecosystem health. We computed BOD by correlating with Normalized Difference Water Index (NDWI). NDWI is sensitive to changes in water content, making it suitable for water quality assessments;

$$\text{NDWI} = (\text{G} - \text{NIR})/(\text{G} + \text{NIR})$$

2000

$$\text{NDWI} = (\text{Band 2} - \text{Band 4})/(\text{Band 2} + \text{Band 4})$$

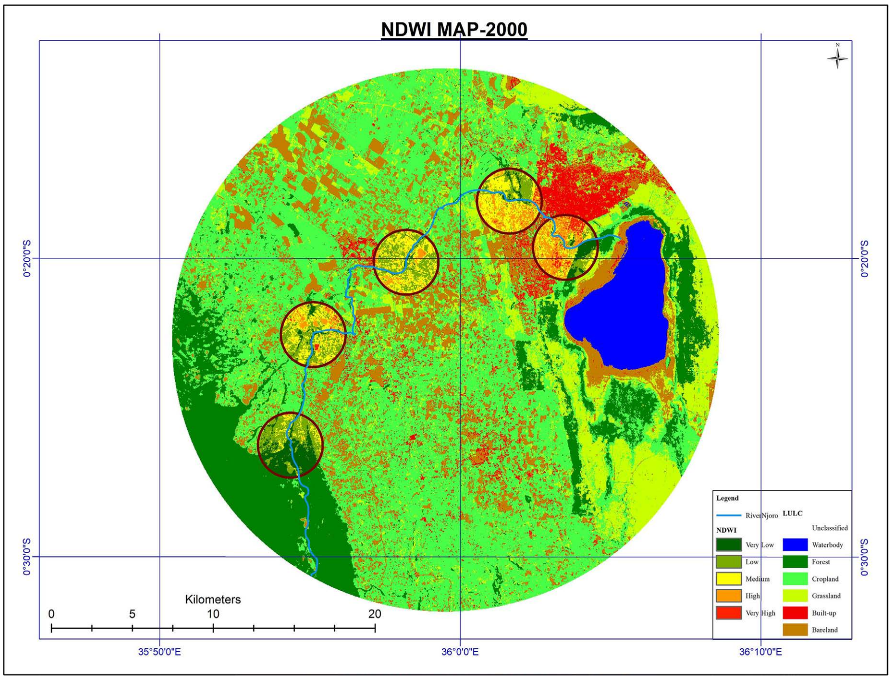

Figure 11. NDWI map 2000.

Table 10. NDWI analysis 2000.

Class	Area (m^2)
Very Low	8973229.156
Low	20367490.88
Medium	21353334.63
High	10503396.77
Very High	1644501.004

NDWI for 2000 ranged from very low to very high (see **Figure 11** and **Table 10**). The areas with very high NDWI values were majorly observed on the urban areas while very low NDWI values were majorly on the forested areas.

2010

$$\text{NDWI} = (\text{Band 2} - \text{Band 4})/(\text{Band 2} + \text{Band 4})$$

NDWI for 2010 ranged from very low to very high as shown in **Figure 12** and **Table 11**. The areas with very high NDWI values were majorly observed on the urban areas while very low NDWI values were majorly on the forested areas.

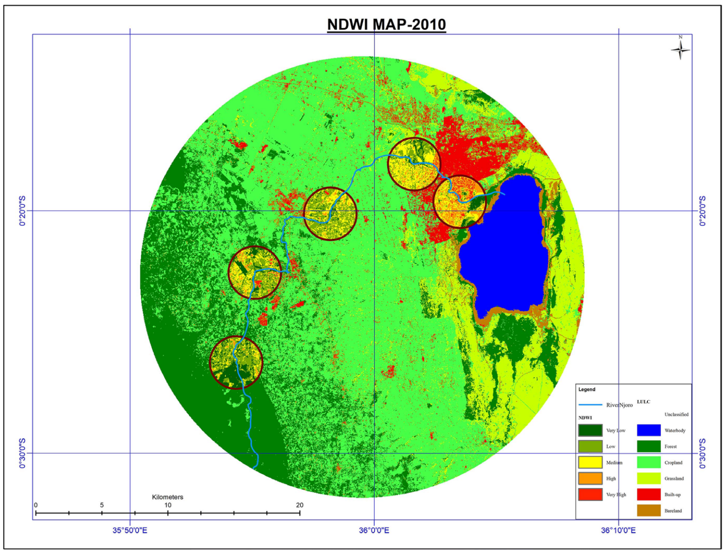

Figure 12. NDWI map 2010.

Table 11. NDWI analysis 2010.

Class	Area (m^2)
Very Low	9,529,803
Low	23,652,319
Medium	19,658,113
High	8,242,732
Very High	1,767,973

2020

$$\text{NDWI} = (\text{Band } 3 - \text{Band } 5)/(\text{Band } 3 + \text{Band } 5)$$

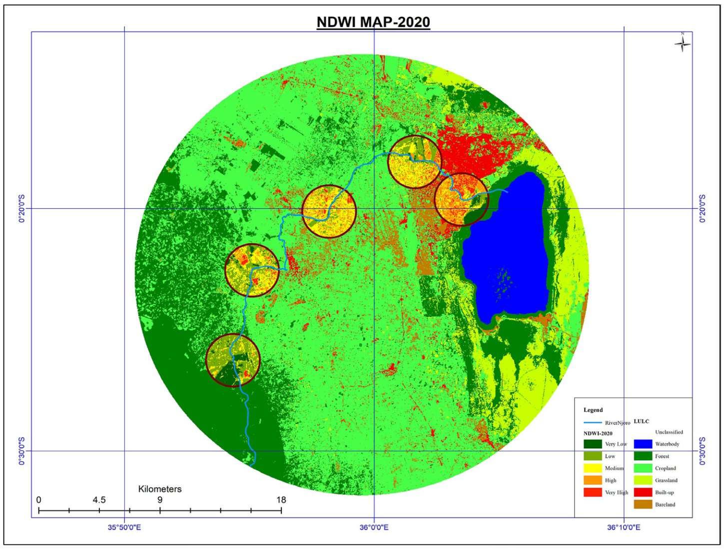

Figure 13. NDWI map 2020.

Table 12. NDWI analysis 2020.

Class	Area (m^2)
Very Low	6,095,632
Low	19,923,610
Medium	21,055,874
High	12,356,151
Very High	3,415,336

NDWI for 2020 ranged from very low to very high (see Figure 13 and Table 12). The areas with very low NDWI values were majorly observed on the forested areas while very high NDWI values were majorly on the urban areas. The NDWI values were changing as compared to 2010 and 2000 NDWI values as shown in Table 13 and Figure 14 below.

Table 13. NDWI trend analysis, 2000, 2010, 2020.

	2000 (%)	2010 (%)	2020 (%)
Very Low	14	15	10
Low	32	38	32
Medium	34	31	33
High	37	13	20
Very High	3	3	5

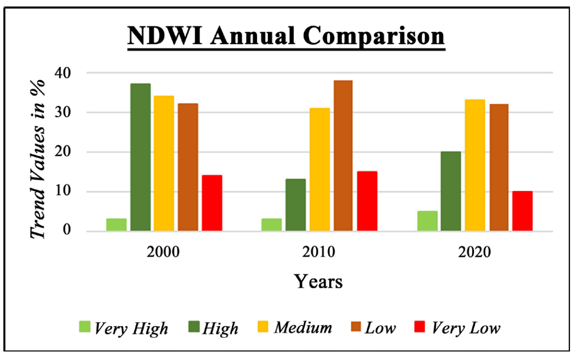

Figure 14. NDWI annual percentages comparison 2000, 2010, and 2020.

3.4.4. Moisture Content

Normalized Difference Moisture Index (NDMI) is a remote sensing technique used to assess vegetation moisture content and monitor changes in water availability over large areas. It is calculated by taking the difference between the near-infrared (NIR) and short-wave infrared (SWIR) bands of satellite imagery, normalized by their sum. Higher NDMI values indicate higher moisture content, while lower values suggest drier conditions showing pollution effects;

$$\text{NDMI} = (\text{NIR} - \text{SWIR})/(\text{NIR} + \text{SWIR})$$

2000

$$\text{NDMI} = (\text{Band 4} - \text{Band 5})/(\text{Band 4} + \text{Band 5})$$

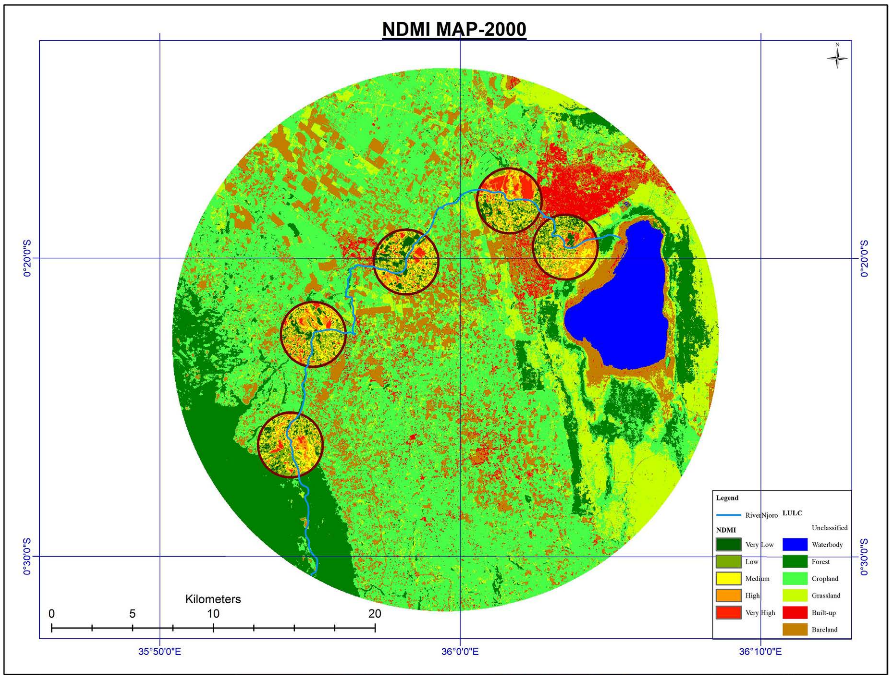

Figure 15. NDMI map 2000.

Table 14. NDMI analysis 2000.

CLASS	Area (m^2)
High	13,030,638
Low	19,038,121
Medium	19,028,880
Very High	4,442,566
Very Low	7,328,602

NDMI for 2000 ranged from very low to very high (see Figure 15 and Table 14). The areas with very high NDMI values were majorly observed on the forested areas while very low NDMI values were majorly on the urban areas.

2010

$$\text{NDMI} = (\text{Band 5} - \text{Band 6})/(\text{Band 5} + \text{Band 6})$$

2020

$$\text{NDMI} = (\text{Band 5} - \text{Band 6})/(\text{Band 5} + \text{Band 6})$$

NDMI for 2020 ranged from very low to very high. The areas with very high NDMI values were majorly observed on the forested areas while very low NDMI

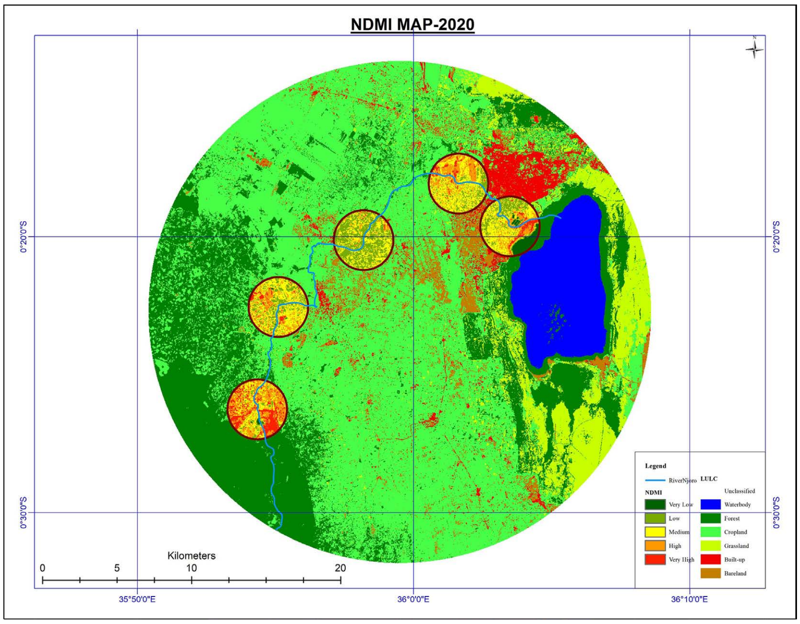

Figure 16. NDMI map 2020.

Table 15. NDMI analysis 2020.

CLASS	Area (m^2)
High	13,867,138
Low	18,800,861
Medium	25,100,333
Very High	3,980,246
Very Low	1,106,972

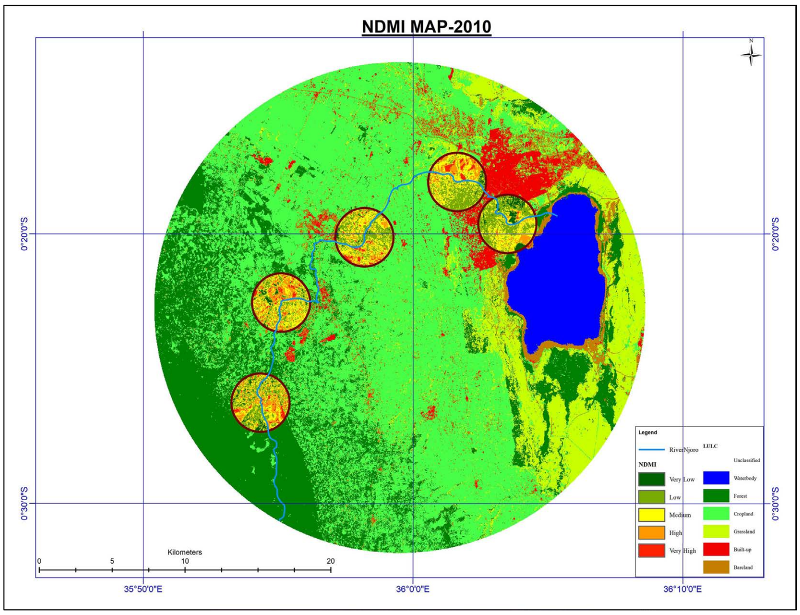

Figure 17. NDMI map 2010.

Table 16. NDMI analysis 2010.

CLASS	Area (m^2)
High	15,845,044
Low	13,232,158
Medium	23,799,586
Very High	6,720,838
Very Low	3,268,289

values were majorly on the urban areas as shown in Figure 16 and Table 15. The NDMI values were increasing as compared to 2010 (shown in Figure 17 and Table 16) and 2000 NDMI values as shown in Table 17 and annual NDMI analysis Figure 18 below.

Table 17. NDMI trend analysis, 2000, 2010, 2020.

	2000 (%)	2010 (%)	2020 (%)
Very Low	12	2	5
Low	30	30	21
Medium	30	40	38
High	21	22	25
Very High	7	6	11

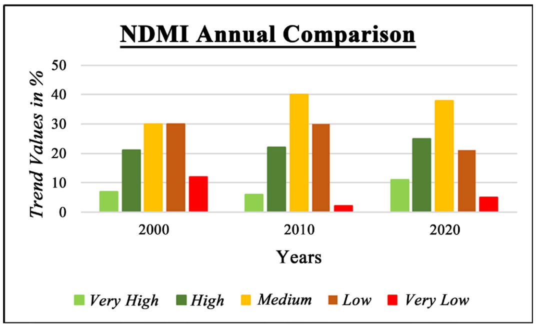

Figure 18. NDMI Annual percentages comparison 2000, 2010, and 2020.

4. Results

Pollution map is generated by combining the computed factors, Nitrogen map, Phosphorous map, NDMI and NDWI map for the 3-time series using the fuzzy overlay tool. Nitrogen map, NDMI, NDWI map and Phosphorous maps are first reclassified into 5 classes. Class one being a class with least Nitrogen value, least Phosphorous value, least NDMI value and least NDWI value to normalize the indices. Fuzzy membership functions for each index are defined to describe how each index contributes to different pollution levels (e.g., low, medium, high) in a fuzzy way.

4.1. Pollution Maps

Pollution map for 2000 (**Figure 19**) ranged from very low to very high as shown in **Table 18**. The areas with very low pollution values were majorly observed on the forested areas while areas with very high pollution values were majorly on the urban areas.

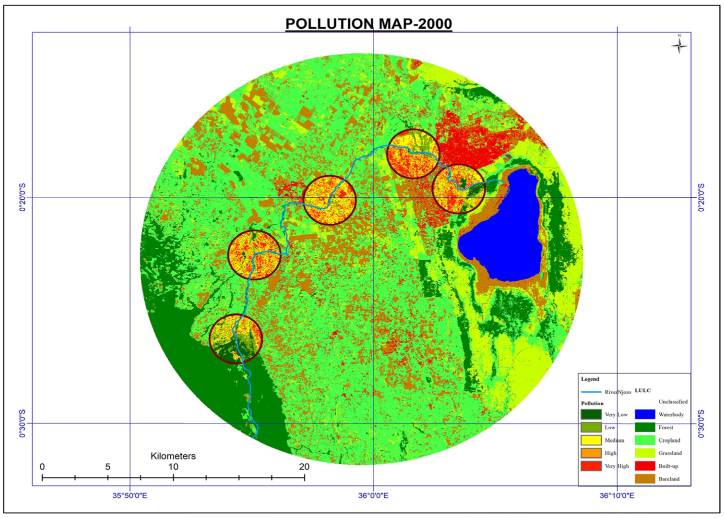

Figure 19. Pollution map 2000.

Table 18. Pollution analysis 2000.

Class	Area (m^2)
High	778604.0324
Low	31347127.74
Medium	13072336.35
Very High	7621.655273
Very Low	17657370.8

4.1.1. Pollution Map 2010

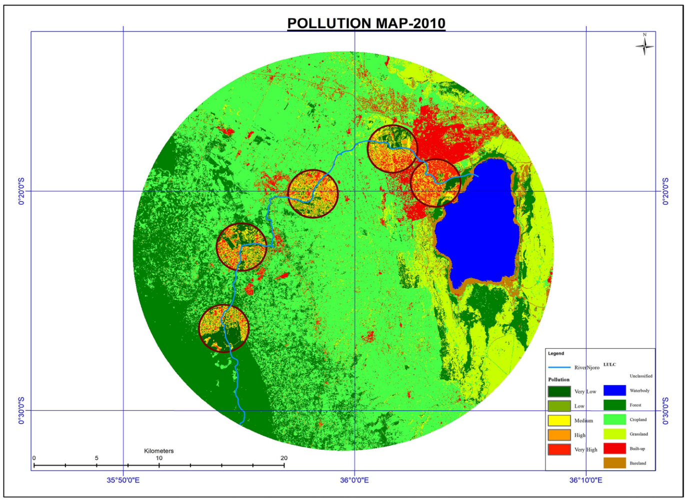

Figure 20. Pollution map-2010.

Table 19. Pollution analysis 2010.

NAME	Area (m²)
High	7,539,270
Low	25,331,693
Medium	22,873,213
Very High	969478.6
Very Low	6,139,074

Pollution map for 2010 ranged from very low to very high (see Figure 20 and Table 19). The areas with very low pollution values were majorly observed on the forested areas while areas with very high pollution values were majorly on the urban areas. The pollution values were increasing as compared to 2000 pollution values.

4.1.2. Pollution Map 2020

Pollution map for 2020 (see Figure 21) ranged from very low to very high as shown in Table 20. The areas with very low pollution values were majorly observed on the forested areas while areas with very high pollution values were majorly on the urban areas. The study demonstrated that the level of pollution to Njoro river has been increasing from 2000 to present as illustrated in Table 21 and Figure 22 below. This is due to the increase in Nitrogen, Phosphorous and BOD levels overtime as shown in Figure 24.

Table 20. Pollution analysis 2020.

NAME	Area (m²)
High	11525973.6
Low	17260279.2
Medium	23674150.2
Very High	4000812.01
Very Low	6396907.21

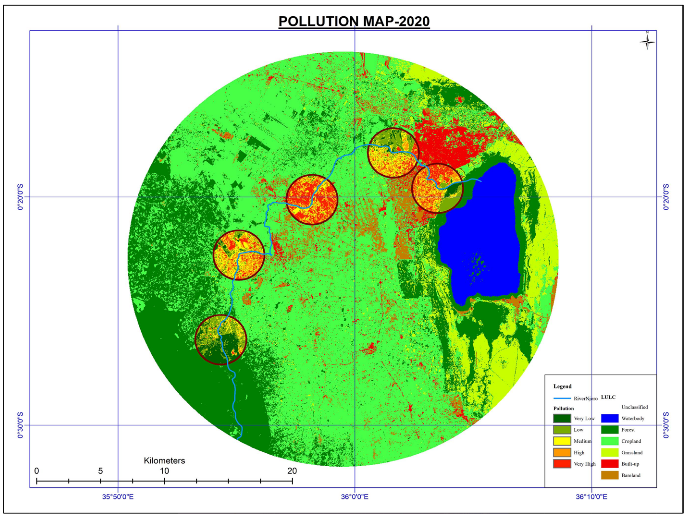

Figure 21. Pollution map 2020.

Table 21. Pollution trend analysis, 2000, 2010 and 2020.

Pollution	2000 (%)	2010 (%)	2020 (%)
Very Low	28	10	10
Low	50	40	28
Medium	21	36	38
High	1	12	18
Very High	0	2	6

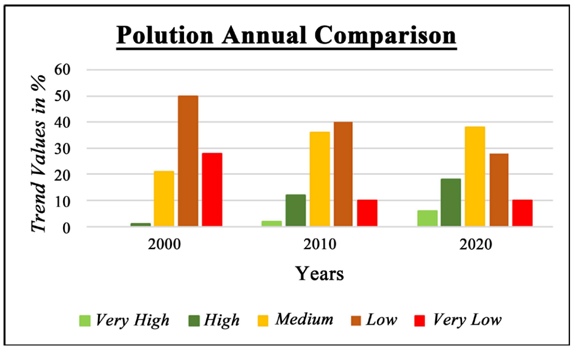

Figure 22. Pollution trend comparison 2000, 2010, and 2020.

4.2. Field Verification and Validation

River Njoro flows from the source in the eastern Mau into Lake Nakuru. We selected the sampling points along river Njoro by taking into consideration the land use land cover along the river and the accessibility to the rivers, that is, the way/route to the sampling points through either the main roads or the feeder roads and we ensured that the samples were uniformly distributed along the river. We ensured that we covered all the LULC classes, that is the forested area which was mainly along the source of the river in the Eastern Mau region, the croplands area which is majorly around Nassuit ward, and Njoro, the grassland area which were somewhere near the mouth of the river in Mwariki area, Bare land areas which were in areas near Kaptembwa, and Kapkures bridge and the built-up areas which were areas around Njokerio, Njoro and the outskirts of Nakuru. We visited sites near the source, Eastern Mau Forest around Tiritagoi, Nassuit, Sigotik, Kapkatet, Mwigito, Ahero, Kenyatta stage, Njoro, Kaptembwa, Rhoda, Kapkures, Baruti, Mogoon, Mwariki and Park View, near the mouth as shown below.

The observation showed an increase in pollution as we approached the mouth, as shown in Figures 23-27, and Figure 28 showing higher pollution as compared to Figure 19, Figure 20, and Figure 21. Which were areas showing lower levels of pollution near the source of the river.

During the site validation visit, several observations were made. Figure 29 shows the local laundry works Kaptembwa bridge, Figure 30 shows heavy sewage effluent contaminating the river at Rhoda area, Figure 31 and Figure 32 show water stagnating at Kapkures bridge and sedimentation and garbage disposal to the river respectively. Finally, eutrophication caused by sewage contamination with river indicating presence of Nitrogen and Phosphorus (see Figure 33).

Figure 23. Photo taken on Monday, 3 PM on 22nd January 2024 showing: River Njoro at Tiritagoi latitude −0.422260˚ longitude 35.908807˚ near the source, Eastern Mau showing minimal pollution. The main activities done around are farming, watering the animals

Figure 24. Photo taken on Monday, 4 PM on 22nd January 2024 showing: River Njoro at Kapkatet, latitude −0.402582˚ longitude 35.913154˚ the main activities around are, watering animals, agriculture and domestic purposes the level of pollution is low.

Figure 25. Photo taken on Monday, 5 PM on 22nd January 2024 showing: River Njoro at Njokerio latitude −0.374421˚ longitude 35.931690˚ showing medium level of pollution, major sources of pollution are domestic waste, and agricultural run-off.

Figure 26. Photo taken on Monday, 5 PM on 22nd January 2024 showing: Surrounding of river Njoro at Njokerio showing how people dumb domestic wastes inappropriately around the river.

Figure 27. Photo taken on Tuesday, 9 AM on 23rd January 2024 showing: River Njoro around Kenyatta, Njoro at latitude −0.329180˚, longitude 35.971820˚ showing medium level of pollution, major activities around the area were agriculture and domestic activities.

Figure 28. Photo taken on Tuesday, 11 AM on 23rd January 2024 showing: River Njoro at Kaptembwa latitude −0.304514˚, longitude 36.040338˚ showing high pollution extents, the main activities around the area are; domestic activities, recreation, agriculture and water watering animals and the main source of pollution were mismanagement of domestic waste and agricultural run-off.

Figure 29. Photo taken on Tuesday, 11 AM on 23rd January 2024 showing: River Njoro at Kaptembwa bridge latitude −0.304514˚, longitude 36.040338˚ showing activities around the area; people doing laundry and young boys diving and swimming in the river.

Figure 30. Photo taken on Tuesday, 2 PM on 23rd January 2024 showing: River Njoro Rhoda latitude −0.311803˚ longitude 36.050506˚ showing that the river is heavily polluted. The main source of pollution are sewage effluents, inappropriate domestic waste disposal and sedimentation.

Figure 31. Photo taken on Tuesday, 4 PM on 23rd January 2024 showing: River Njoro showing Sewage effluent at Kapkures bridge latitude −0.311803˚ longitude 36.050506˚, the river is heavily polluted, and the water is stagnant at some point being a risk to waterborne diseases.

Figure 32. Photo taken on Tuesday, 5 PM on 23rd January 2024 showing: River Njoro, Mwariki bridge at latitudes −0.326908˚ longitude 36.064971˚ showing Sedimentation and garbage. The main sources of pollution are inappropriate disposal of solid waste, sedimentation and sewage effluents. The main activity in the area is watering animals.

Figure 33. Photo taken on Tuesday, 5 PM on 23rd January 2024 showing: River Njoro near Mwariki bridge latitudes −0.326908˚ longitude 36.064971˚ showing Eutrophication, caused by Sewage effluents clearly showing presence of Nitrogen and phosphorous pollution in the area.

5. Discussion

Our analysis showed decrease in the water quality over time showing an increase in pollution rate from 1% to 14% to 24% for the periods between 2000, 2010 and 2020 respectively. Contaminated water causes waterborne diseases which may lead to death. In order to thrive as a society, we need a healthy eco-system an environment where people use good quality water and is easily accessed without being in a risk of water borne diseases (El-Zeiny & El-Kafrawy, 2017; Bollinger et al., 1999; Fauvet et al., 2001; Kılıç, 2021).

High phosphorous and nutrients levels cause soil acidification which in turn causes changes in land use and land cover, leading to the loss and degradation of wetlands, which play a crucial role in water filtration and nutrient cycling which reduces the capacity to absorb and filter pollutants (Bollinger et al., 1999).

Polluted water expelled into the lake causes algae blooms due to proliferation of newly introduced nutrients (phosphorous and nitrogen), which in turn reduces the oxygen levels in the water (eutrophication). Eutrophication causes aquatic life death due reduced oxygen levels in the river which are depleted or are at a very minimum level before being deposited to the lake (Herut et al., 2000).

High levels of phosphorous and nitrogen contamination cause algae blooms that produce algal toxins which are be harmful to human and animal health.

6. Conclusion

From the summary of findings, the study concludes that River Njoro has been perceived by residents of informal settlements as the most convenient and cheapest way of disposing of sewage and solid waste. The perceptions and attitudes of residents towards River Njoro revealed that the residents along the river have little sentimental attachment to the river and instead view it merely as a convenient and cheap way of disposing their wastes. The reasons given for this were that firstly, the settlement lacked an effective solid waste management system, and secondly, it lacked adequate sanitation infrastructure in terms of ablution blocks and a municipal sewer connection.

In regard to how the pollution of River Njoro is affecting the ecosystem, the study concludes that pollution within the area has had negative adverse effects on agricultural land, soils, quality of water and aquatic life. There is need for environmental protection of this water source for the safety of human and aquatic livelihoods in the area.

7. Recommendation

From the reviewed literatures and based on the results the following recommendations are made not only to enhance the water quality and the environment, but also to protect the aquatic life who depend on the surface water of river Njoro:

1) In order to lessen the influence on water quality and pollution-related health issues, a management strategy that restricts the dumping of garbage into surface water bodies is required. This can be accomplished by implementing an efficient waste management plan and offering a dependable public water supply.

2) Establish Low-Cost IoT Water Quality monitoring station that will provide real time water quality condition enhancing Timely decision-making process for the Authorities and the communities. Additionally install the sensors at discharge points near the Industrial companies to enforce discipline.

3) Incorporate a waste management plan for the municipality with a focus on reducing domestic and industrial effluents to the river. This should be supported by the availability of sustainable water supply infrastructure which will in turn reduce pollution significantly, protecting the quality of water.

For household pollution, the environmental and public health regulators should conduct community training and community engagement in river conservation to ensure they have the knowledge, best practices and understand the importance of river conservation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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