Habitat assessment for seasonal variation of river pollution in Ibadan, Nigeria, in a geographic information systems interface

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Summary
More accurate spatio-temporal predictions of urban environment are needed as a basis for assessing exposure in environmental studies and to inform urban protection policy and management authorities. Using habitat assessment protocol, the author assesses the pollution status of rivers in Ibadan, Nigeria. Data used include hydrographic feature data and habitat assessment data. These basic environmental components are the result of the integration of a wide range of relatively independent factors which enable a more complex analysis of the environment in urban areas. Geographic information systems were used for data management, input and output of data and visualisation. The pollution status of the inland rivers assessed during the rainy season (July to September) and dry season (October to March) in the eleven local government areas in Ibadan suggested that out of the twenty-two sample points, seven (31.8%) and six (27.3%) were slightly polluted and nine (40.9%) and ten (45.4%) were moderately polluted during the rainy and dry seasons, respectively. The environmental models are focused on the assessment of surface-water quality of habitat in relation to human activities. Although the models are calibrated and tested by application in the metropolitan area of Ibadan, the structure of this project is applicable to other similar areas.

Keywords
Geographic information system, Habitat assessment, Ibadan, Nigeria, Pollution, River, Seasonal trend.

Controlli ambientali sulla variazione stagionale dell'inquinamento dei fiumi a Ibadan, attraverso l'uso di un'interfaccia con i sistemi informativi geografici

Riassunto
Più accurate predizioni spazio-temporali dell'ambiente urbano sono necessarie come base per studi di controllo ambientale e per lo sviluppo di un'adeguata politica di protezione ad uso delle istituzioni. Il presente studio si occupa della verifica del livello di inquinamento dei fiumi a Ibadan, Nigeria, attraverso l'uso di un protocollo di controllo ambientale. I dati utilizzati comprendono le informazioni inerenti le caratteristiche idrografiche e quelle per il controllo ambientale. Questi fattori ambientali di base vanno ad integrare una serie di ulteriori variabilità che permettono un'analisi più completa ed articolata dell'ambiente nelle aree urbane. I sistemi informativi geografici vengono in genere utilizzati per l'immissione e gestione dei dati, e per la visualizzazione. Dalla misurazione del livello di inquinamento dei fiumi interni nelle undici zone a governo locale a Ibadan, misurato durante la stagione delle piogge (da luglio a settembre) e durante la stagione secca (da ottobre a marzo), emerge che, dai ventidue punti di campionamento rispettivamente, la zona sette

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(31,8%) e la sei (27,3%) erano lievemente inquinate, la nove (40,9%) e la dieci (45,4%) moderatamente inquinate sia durante la stagione delle piogge sia in quella asciutta. I modelli ambientali si concentrano sul controllo delle acque di superficie in relazione alle attività umane che influiscono sull'ambiente. Sebbene i modelli siano calibrati e testati sull'area urbana di Ibadan, il sistema utilizzato in questo progetto può essere utilizzato anche per aree con analoghe caratteristiche.

Parole chiave

Andamento stagionale, Controllo ambientale, Fiume, Ibadan, Inquinamento, Nigeria, Sistema informativo geografico.

Introduction

The basic unit in water resources management is the river basin or hydrographic catchments, and the network of draining channels, the river network that collects and conveys surface water. River reaches, dams and reservoirs, diversion and pumping stations, water works and secondary distribution networks are all spatially distributed elements of this system. The elements of water resources management are distributed in space. Their location, surroundings and spatial relationships are critical for the resulting flow characteristics and the quality of the water resources and, thus, their availability for different types of use. River basin management has obvious spatial dimensions since it is focused on a spatial unit, the hydrological catchments, in the first place.

Consequently, geographic information systems (GIS) are one of the tools that can be used for their analysis. This makes the use of GIS, and its integration with traditional water resources models, an obvious strategy for the development of river basin management systems (7). While GIS is used to capture, analyse and display spatial data, the models provide the tools for complex and dynamic analysis. Input for spatially distributed models, as well as their output, can be treated as map overlays and topical maps (6). The familiar format of maps supports the understanding of model results, but also provides a convenient interface to spatially referenced data. Expert systems, simulation and optimisation models offer the possibility of adding complex and dynamic analysis to the GIS.

Habitat assessment is defined as the evaluation of the structure of the surrounding physical habitat that influences the quality of the water resource and the condition of the resident aquatic community (2). The alteration of the physical structure of the habitat is one of five major factors of human activities described by Karr and Chu (11) that degrades aquatic resources. Habitat, as structured by in-stream and surrounding topographical features, is a major determinant of aquatic community potential (1, 12). Both the quality and quantity of available habitat affect the structure and composition of resident biological communities. Final conclusions regarding the presence and degree of biological impairment should thus include an evaluation of habitat quality to determine to what extent the habitat might be a limiting factor. This study therefore assesses the pollution status of rivers in the metropolitan area of Ibadan using habitat quality as an index; results are presented using GIS as an interface. It is expected that this study will be useful to Nigerian urban development authorities and to environmental protection agencies when formulate their policies and programmes for planning and management of freshwater resources in Nigeria.

Materials and methods

Study area

Ibadan, Oyo state, Nigeria (Fig. 1) is the largest city in West Africa and the second largest in Africa, covering an area of 240 km². The city is located on longitude 3°5′E and latitude 7°20′N (9).

Sources of data

All data were collected as part of another study (O.K. Adeyemo, unpublished data). Hydrographic features and habitat assessment data were collected from the river system in the eleven local government areas in Ibadan, comprising Akinyele, Egbeda, Ibadan north, Ido, Ibadan north-west, Ibadan north-east, Ibadan south-west, Ibadan south-east, Lagelu, Ona-ara and Oluyole local government areas (Fig. 1). This paper synthesises the data in a form that is appropriate for GIS presentation and appreciation.

Hydrographic feature data

Hydrographic feature data provide a spatial frame of reference for analysis. The hydrographic features utilised are rivers, streams and watershed boundaries sampled during the period of this study. In a GIS, these data will be represented visually in a map layer. However, unlike static maps, these features will be associated with descriptive data. Thus, selecting a body of water or watershed will instantly provide a user with the unique identifying name or number of a feature, as well as other qualitative and quantitative information. In the context of this study, this is useful in assigning an

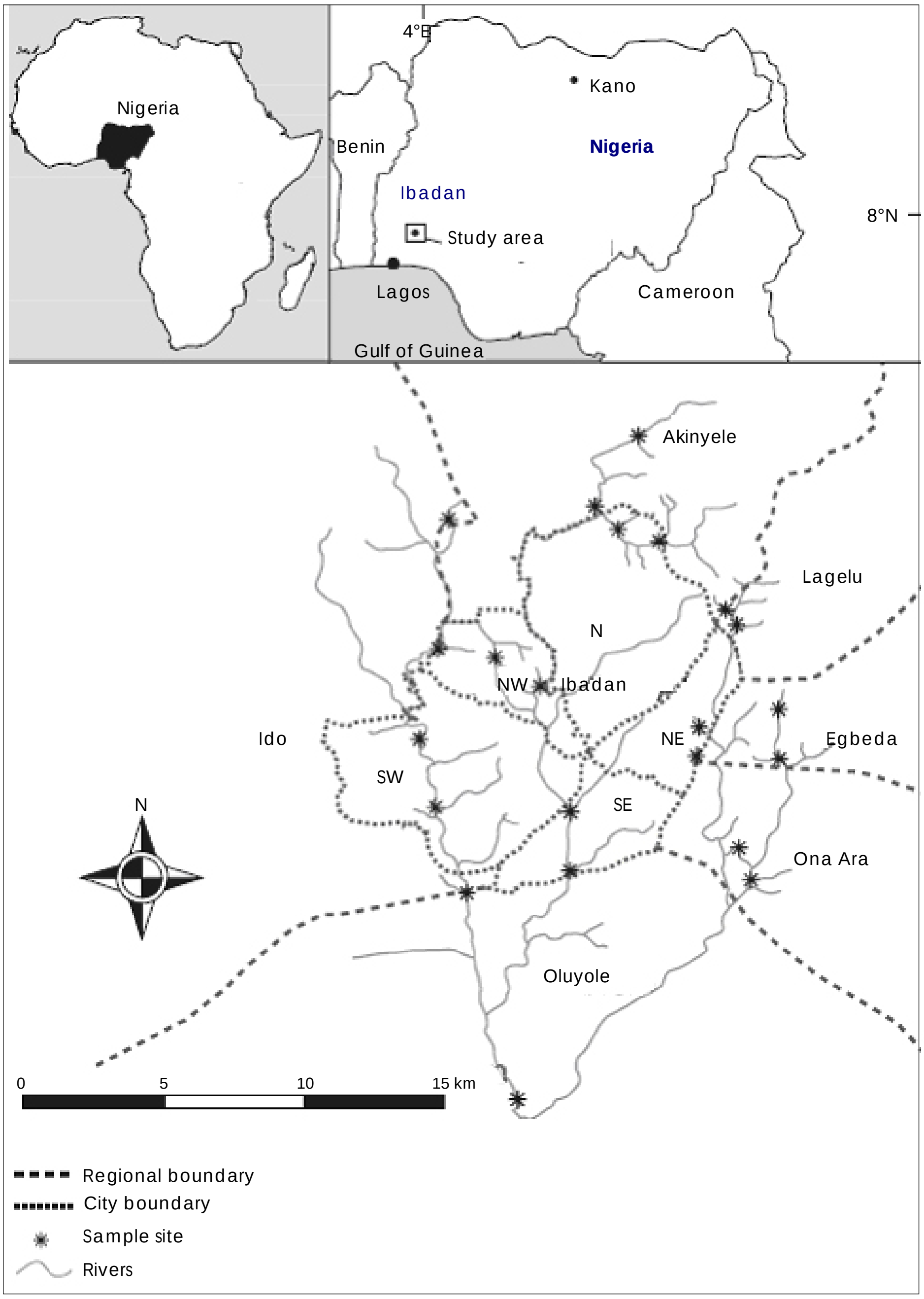

Figure 1
Map of the city of Ibadan, indicating the sampling points

impairment status to watersheds and seeing the relationships between such impairments and other spatially relevant variables (i.e. land use practices).

Habitat assessment data

The habitat quality evaluation was accomplished by characterising selected habitat parameters through systematic habitat assessment using a modified United States Environmental Protection Agency (EPA) national standardised method of physical characterisation/water quality protocol (16, 18). The following were measured at each sampling site (22 sites in all):

- geographic coordinates of location using global positioning system
- river velocity and depth
- epifaunal cover
- turbidity, sediment deposition and human activity in the area.

Key features measured were then rated as poor, marginal, suboptimal or optimal (Table I) to provide a consistent assessment of habitat quality (16, 17).

Physical characterisation protocol

Physical characterisation parameters include estimations of general land use and physical stream characteristics, such as width, depth, flow and substrate. The evaluation begins with the riparian zone (stream bank and drainage area) and proceeds to in-stream sediment/substrate descriptions. The information collected during the physical characterisation aspect includes the following:

Land use data

The land use/land cover classification scheme provides information about the specific human activities of that area which was classified as follows: residential, commercial, industrial, transportation and farming.

Estimated stream velocity, width and depth (in meters)

Stream velocity in a representative run area was estimated. The distance from shore to shore at a transect representative of the stream width and the vertical distance from water surface to stream bottom at a representative depth at each of the habitats were also estimated.

Table I
Classification of water quality status of the sampled locations based on key features of the assessed habitats

Habitat parameter	Optimal	Suboptimal	Marginal	Poor
Epifaunal cover	>70% epifaunal colonisation and fish cover (submerged logs, cobbles) or other stable habitat	40-70% mix of stable habitat	20-40% + habitat availability, less stable	<2% stable habitat plus substrate unstable or absent
Velocity/ depth	All four velocity/depth regimes present (i.e. slow-deep, slow-shallow, fast-deep and fast-shallow)	Only three of the four regimes present	Two of the four regimes present	Dominated by one of the regimes (usually slow)
Sediment deposition	Less than 5% of bottom affected by sediment deposition	5-30% of the bottom affected by sediment deposition	30-50% affected, e.g. at obstructions and bends	>50% sediment loading to heavy deposition
Turbidity	Clear – free from cloudiness, allowing light to pass through	Slightly turbid – a very small amount of haziness in the body of the water	Turbid- cloudiness or haziness due to matter in suspension	Opaque – transparent or translucent (i.e. it does not allow light to pass through)

Adapted from United States Environmental Protection Agency, 2001 (18)

Sediment deposits

Deposits present in the sampling area and the presentation of the undersides of rocks not deeply embedded (if they are black this generally indicates low dissolved oxygen or anaerobic conditions) were observed.

Turbidity

The amount of material suspended in the water column was described based upon visual observation.

Epifaunal substrate/available cover

The epifaunal substrate includes the relative quantity and variety of natural structures in the stream, such as cobble (riffles), large rocks, fallen trees, logs, branches and undercut banks, available as refugia, feeding, or sites for spawning and nursery functions of aquatic macro fauna. A wide variety and/or abundance of submerged structures in the stream provide macro invertebrates and fish with a large number of niches, thus increasing habitat diversity.

The water quality of each site sampled was also qualified as being optimal, suboptimal, marginal or poor, based on the criteria described in Table I.

The relative proportions of the various organisms in a sample are determined and the quality of the water is then inferred by comparing the habitat diversity of the sampled location with the expected ratios in unpolluted habitats of the type under investigation (16, 17, 18). The assessment procedure also takes into account other relevant factors, such as the intensity of algal and/or weed development, water turbidity, bottom siltation, nature of the substratum, speed of current and water depth. The biological information of each site is then condensed into a readily understandable form by means of a 5-point biotic index (Q values), an arbitrary system in which habitat diversity and water quality is related and scored as described below (16, 18).

Biotic index (Q value) water quality

The following indices are used:

- 5 (habitat diversity high) good
- 4 (habitat diversity slightly reduced) fair
- 3 (habitat diversity significantly reduced) doubtful
- 2 (habitat diversity low) poor
- 1 (habitat diversity very low) bad.

Intermediate values, e.g. Q3-4 or Q1-2, are used to describe conditions where appropriate.

The Q value was then used to determine the pollution status of the sites sampled, based on its ability to support flora and fauna, determined here by habitat diversity. In the interests of simplicity, four main classes of water quality were defined. These relate to the Q value scale and indicate the degree of pollution of each site as explained below.

Quality ratings category of river water quality

The following quality ratings were used:

- Q5, Q4-5, Q4: unpolluted
- Q3-4: slightly polluted
- Q3, Q2-3: moderately polluted
- Q2, Q1-2, Q1: seriously polluted.

Data analysis

Using a map of Ibadan showing the rivers and drainage system as the base map and universal transverse mercator geographic coordinate system, the data generated from the hydrographic feature and habitat assessment protocol were used to generate maps depicting the pollution status of the study area, using ArcView 3.2™ software, (Environmental Systems Research Institute, Inc., Redlands, California).

Results and discussion

Results of the habitat assessment protocol during rainy and dry seasons are presented in Tables II and III. The percentage of the sample locations based on the water quality rating for the different parameters (epifaunal cover, velocity/depth, turbidity, sediment deposition and the overall quality) is presented in Tables IV and V. The GIS mapping of the pollution status of the study area showing overall habitat quality during rainy and dry rainy seasons are presented as Figures 2 and 3, respectively. The parameters assessed for the habitat assessment protocol revealed that the activity in the watershed was the same during

Table II
Determination of water quality of rivers in Ibadan using habitat assessment parameters during the rainy season

Local govern-ment area (LGA)	Sample point	Epifaunal cover	Activity area	Velocity/ depth	Turbidity	Sediment depo-sition	Overall assess-ment
Akinyele LGA downstream	Ajibode	Marginal	Farming	Marginal	Marginal	Poor	Q2
Akinyele LGA upstream	IITA	Marginal	Farming	Marginal	Poor	Poor	Q2
Ibadan North LGA downstream	Orogun Express	Sub-optimal	Residential	Marginal	Marginal	Sub-optimal	Q3
Ibadan North LGA upstream	Orogun Bridge	Sub-optimal	Commercial	Marginal	Marginal	Marginal	Q2
Iddo LGA downstream	Eleyele Bridge	Sub-optimal	Residential	Marginal	Marginal	Marginal	Q2
Iddo LGA upstream	Apete Bridge	Marginal	Residential	Poor	Marginal	Poor	Q2
Ibadan north-west LGA downstream	Isaac Oil	Marginal	Commercial	Poor	Poor	Marginal	Q2
Ibadan north-west LGA upstream	Fan Milk Valley	Poor	Commercial	Poor	Poor	Marginal	Q1
Ibadan south-west LGA downstream	Oluyole Estate	Sub-optimal	Commercial	Marginal	Marginal	Sub-optimal	Q3
Ibadan south-west LGA upstream	IAR&T Bridge	Sub-optimal	Residential	Marginal	Marginal	Marginal	Q2
Ona Ara LGA downstream	Abonde Village	Optimal	Residential	Sub-optimal	Marginal	Sub-optimal	Q3-4
Ona Ara LGA upstream	Ogbere TI – O – YA	Optimal	Residential	Sub-optimal	Sub-optimal	Sub-optimal	Q4
Egbeda LGA downstream	Onideure Efun Old Ife Rd	Sub-optimal	Residential	Marginal	Sub-optimal	Marginal	Q3
Egbeda LGA upstream	New Gbagi Market	Sub-optimal	Commercial	Marginal	Marginal	Marginal	Q2
Ibadan north-east LGA downstream	CAC Oremeji Express	Sub-optimal	Commercial	Poor	Marginal	Sub-optimal	Q3
Ibadan north-east LGA upstream	Ogbere at Ife Rd	Sub-optimal	Commercial	Poor	Marginal	Marginal	Q2
Ibadan south-east LGA downstream	Ogunpa at Lagos-Ibadan Express Rd	Poor	Commercial	Poor	Poor	Poor	Q1
Ibadan south-east LGA upstream	Ogunpa at Ibadan Grammar School Molete	Marginal	Commercial	Marginal	Poor	Marginal	Q2
Lagelu LGA downstream	Akobo Estate	Sub-optimal	Residential	Marginal	Sub-optimal	Marginal	Q3
Lagelu LGA upstream	Akobo	Marginal	Farming	Poor	Marginal	Marginal	Q2
Oluyole LGA downstream	Odo Ona Elewe	Marginal	Commercial	Marginal	Poor	Poor	Q2
Oluyole LGA upstream	New Garage Barrack Orita Challenge	Sub--optimal	Pig farm	Sub-optimal	Marginal	Poor	Q3

Habitat assessment quality ratings category of river water quality

Q5, Q4-5, Q4	unpolluted
Q3-4	slightly polluted
Q3, Q2-3	moderately polluted
Q2, Q1-2, Q1	seriously polluted

Table III
Determination of water quality of rivers in Ibadan using habitat assessment parameters during the dry season

Local government area (LGA)	Sample point	Epifaunal cover	Activity area	Velocity/ depth	Turbidity	Sediment depo-sition	Overall assess-ment
Akinyele LGA downstream	Ajibode	Poor	Farming	Marginal	poor	Poor	Q1
Akinyele LGA upstream	Iita	Marginal	Farming	Marginal	Marginal	Poor	Q2
Ibadan North LGA downstream	Orogun Express	Marginal	Residential	Marginal	marginal	Poor	Q2
Ibadan North LGA upstream	Orogun Bridge	Marginal	Commercial	Marginal	Sub-optimal	Poor	Q2
Iddo LGA downstream	Eleyele Bridge	Sub-optimal	Residential	Marginal	Sub-optimal	Sub-optimal	Q4
Iddo LGA upstream	Apete Bridge	Poor	Residential	Poor	Poor	Poor	Q1
Ibadan north-west LGA downstream	Isaac Oil	Marginal	Commercial	Marginal	Poor	Poor	Q2
Ibadan north-west LGA upstream	Fan Milk Valley	Poor	Commercial	Marginal	Poor	Poor	Q1
Ibadan south-west LGA downstream	Oluyole Estate	Marginal	Commercial	Marginal	Sub-optimal	Marginal	Q2
Ibadan south-west LGA upstream	IAR&T bridge	-optimal	Residential	Marginal	Sub-optimal	Sub-optimal	Q3-4
Ona Ara LGA downstream	Abonde Village	Sub-optimal	Residential	Marginal	Sub-optimal	Marginal	Q3
Ona Ara LGA upstream	Ogbere TI - O - YA	Marginal	Residential	Marginal	Sub-optimal	Marginal	Q2
Egbeda LGA downstream	Onideure Efun Old Ife Rd	Marginal	Residential	Marginal	Marginal	Poor	Q2
Egbeda LGA upstream	New GBAGI Market	Sub-optimal	Commercial	Marginal	Sub-optimal	Marginal	Q3
Ibadan north-east LGA downstream	CAC Oremeji Express	Marginal	Commercial	Marginal	Sub-optimal	Sub-optimal	Q3
Ibadan north-east LGA upstream	Ogbere at Ife Rd	Sub-optimal	Commercial	Marginal	Sub-optimal	Sub-optimal	Q3-4
Ibadan south-east LGA downstream	Ogunpa at Lagos-Ibadan Express Rd	Poor	Commercial	Marginal	Poor +	Sub-optimal	Q1
Ibadan south-east LGA upstream	Ogunpa at Ibadan Grammar School Molete	Poor	Commercial	Marginal	Sub-optimal	Poor	Q2
Lagelu LGA downstream	Akobo Estate	Sub-optimal	Residential	Marginal	Sub-optimal	Marginal	Q3
Lagelu LGA upstream	Akobo	Marginal	Farming	Marginal	Poor	Marginal	Q2
Oluyole LGA downstream	Odo Ona Elewe	Marginal	Commercial	Marginal	Poor	Poor	Q1
Oluyole LGA upstream	New Garage Barrack Orita Challenge	Sub-optimal	Pig farm	Marginal	Sub-optimal	Marginal	Q3

Habitat assessment quality ratings category of river water quality

Q5, Q4-5, Q4	unpolluted
Q3-4	slightly polluted
Q3, Q2-3	moderately polluted
Q2, Q1-2, Q1	seriously polluted

Table IV
Quality of sample points (percentage) based on each habitat assessment parameters during the rainy season

Water quality rating	Epifaunal cover	Velocity/depth	Turbidity	Sediment deposition
Optimal	9.1%	–	–	14.1%
Suboptimal	50%	13.6%	13.6%	8.6%
Marginal	31.8%	54.5%	59.1%	50%
Poor	9.1%	31.8%	27.3%	27.3%

Table V
Quality of sample points (percentage) based on each habitat assessment parameters during the dry season

Water quality rating	Epifaunal cover	Velocity/depth	Turbidity	Sediment deposition
Optimal	4.5%	–	–	14.2%
Suboptimal	27.3%	–	54.5%	8.6%
Marginal	45.4%	95.4%	13.6%	31.8%
Poor	8.6%	4.5%	31.8%	45.4%

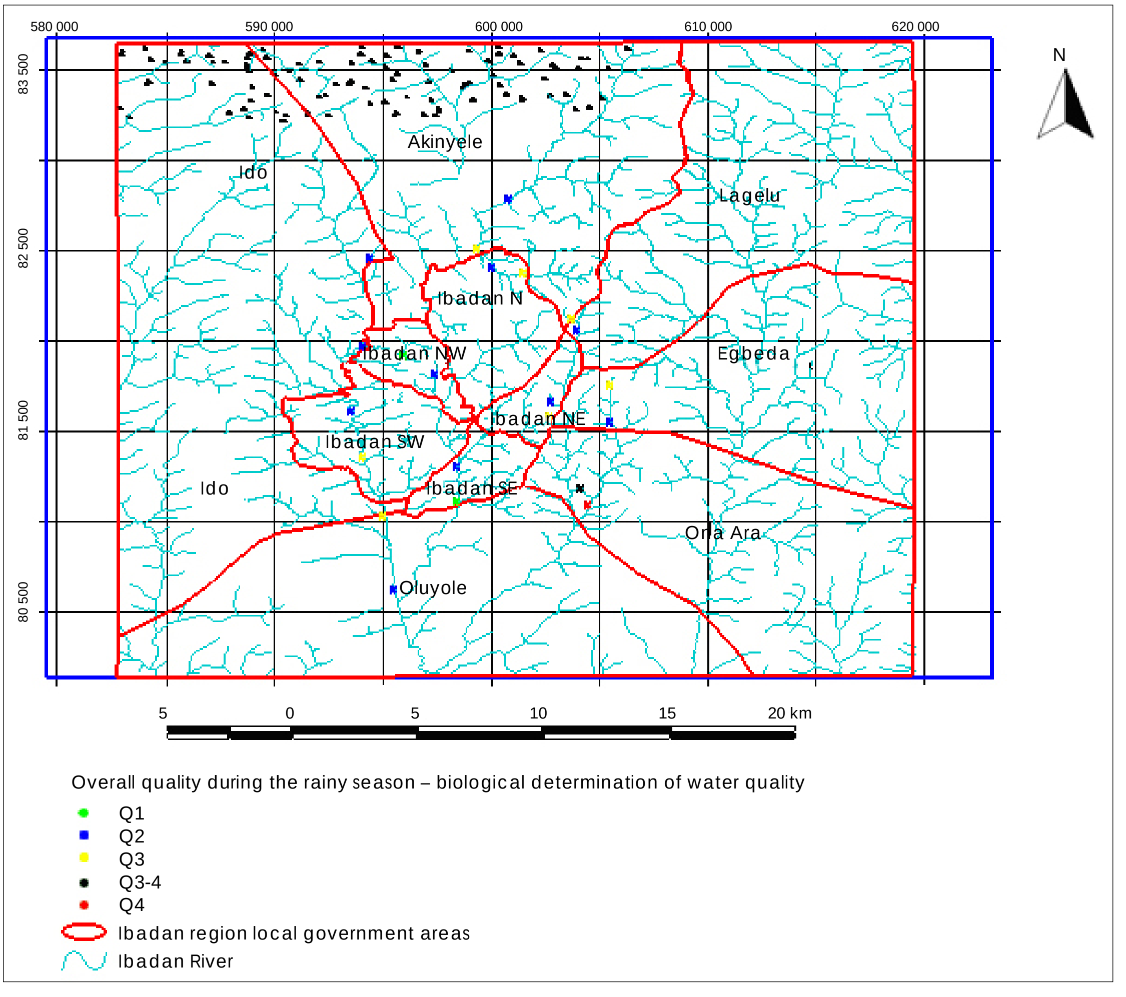

Figure 2
Study area showing overall habitat quality during the rainy season

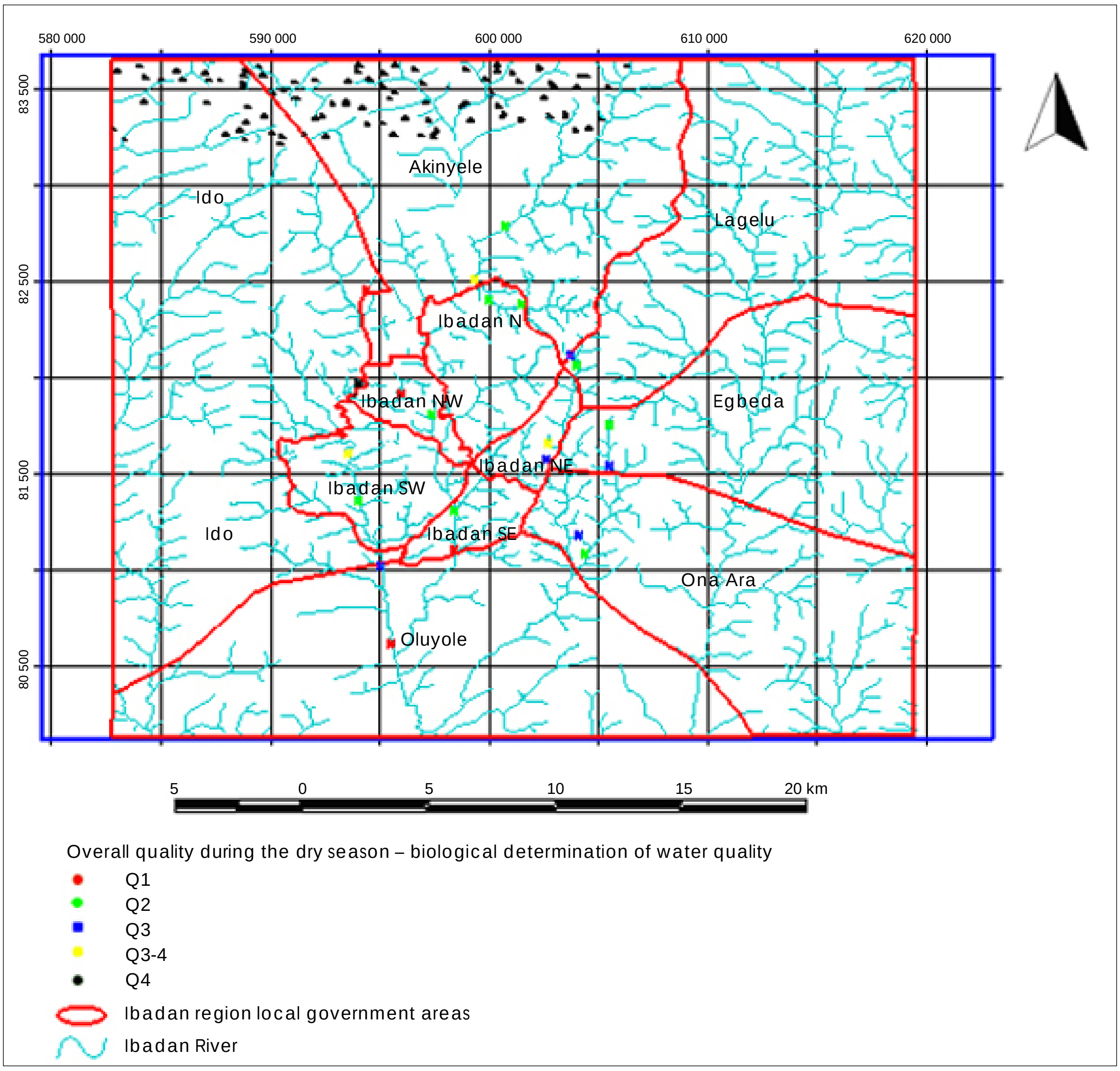

Figure 3
Study area showing overall habitat quality during the dry season

the two seasons; four (18.2%) of the sampled points had farming activities in progress, eight (36.4) were residential areas, while in ten (45.4%) places, commercial activities were observed. This is quite typical of a metropolitan city like Ibadan.

The result of the overall sensitivity of the inland rivers assessed in the eleven local government areas in Ibadan (Fig. 1) suggested that out of the twenty-two sample points, seven (31.8%) and six (27.3%) were slightly polluted, nine (40.9%) and ten (45.4%) were moderately polluted during the rainy and dry seasons, respectively. Two (9.1%) were seriously polluted, one (4.5%) was exceptionally polluted and three (13.6%) sample points were unpolluted during the two seasons.

Since many biological phenomena and human activities are water dependent, the watershed is a natural unit of study when assessing ecological stress. A watershed is the land area drained by a stream and is delineated by topography. Given that surface water drains to one outlet in a watershed or subwatershed, the land activities upstream affect the water quality and quantity at that point. The spatial pattern of measured water quality parameters helps to interpret the relationship between land use and water quality (5). The assessment of the habitat parameters in this study was useful in determining the pollution status of the rivers in the study area (Tables II and III).

The overall sensitivity or pollution status based on all of the habitat parameters assessed was imputed and presented in a GIS interface (Figs 2 and 3). Recently, many publications have explored the utility of GIS and remote-sensed imagery to approximate the regional causes of water pollution (3, 4, 10). In these studies, water pollution data is placed in a geographic context to see what generalisations can be made concerning the impact of regional land use practices on water quality. Such findings can be useful in the remediation of impaired watersheds and in identifying unexamined watersheds with a high risk of impairment. These methods are particularly useful in evaluating the causes of non-point source (NPS) pollution, where the sources of pollution are diffuse and dependent on the health of an entire watershed, as is the case in the present study. It has also been widely documented that land use practices and non-point contamination can be correlated with inland water quality (8, 14, 13, 15).

The results of this study show that the water quality of a watershed is prone to seasonal fluctuations depending on the parameter assessed. Epifaunal cover, river velocity/depth and sediment deposition were generally of superior quality and therefore more suitable for aquatic life during the rainy season while turbidity was generally better during the dry season. The information generated from the habitat assessment protocol (Tables II and III) provided an insight as to the ability of the sampled stream to support a healthy aquatic community. This study therefore suggests that an evaluation of habitat quality is critical to the assessment of ecological integrity and should be performed at each site at the time of biological sampling.

Conclusions

The spatio-temporal mapping of the pollution status of the sampled rivers in Ibadan (Figs 2 and 3), on the basis of hydrographic features data, is a valuable tool for spatially defining and delimiting the pollution problems. This represents the first step that is necessary for planning subsequent corrective actions. It will also enable the prioritisation of remediation efforts. Consequently, it is recommended that multiple water quality sampling and monitoring over a longer period of time be conducted to provide a more comprehensive picture of the pollution status of the Ibadan river system. Further studies on the use of other GIS tools, such as the development of bioaccumulation risk index and predictive models for contaminated areas, are also recommended.

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