

Rural and Urban Planning in Developing Countries: Site Selection for Disposal of Water Treatment Residuals Using Geographic Information Systems (GIS)

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Abstract: The study proposes a conceptual framework for site selection disposal of water treatment residuals in developing countries using geographic information systems. The conceptual framework comprises 3 methodological factors, namely selection of case studies, database development and management and analysis of data and presentation of results or 4 stages, namely raw data, parameter maps, processing and final product. It is envisaged that this theoretical model provides a useful tool for rural and urban planner's practitioners in developing a more comprehensive overall planning strategies.

Key words: Rural and Urban planning, developing countries, site selection, disposal of water treatment residuals, GIS

INTRODUCTION

Rural and urban planning is a complex process that requires the harmonization of a wide range of variables. In developing countries, most urban settlements are still being planned using non-digital techniques, while the rural areas are not formally planned in most cases (Enplan Group, 1997). This leads to the formulation of Masterplans that are limited in scope, functionality and sustainability. One of major aspect of rural and urban planning is the location of water source intakes, treatment plants and sites for the disposal of the water treatment residuals.

The search for new sources of water is never ending in most developing countries. Populations are increasing rapidly consequently water demand increases to cope. This has forced many countries into sourcing water from rivers, streams and other surface and sub-surface sources. Quite often, water from these sources requires extensive treatment before it is made potable in line with World Health Organization Standards (Marhaba, 2000).

Full treatment of water may comprise pre-treatment (with or without chemicals), mixing, coagulation, flocculation, settlement, filtration and sterilization. In any given case, the amount of treatment required is usually

first decided before consideration is given to the best way of providing it. Furthermore, the disposal of the waste evolving from the treatment processes should also influence the location, layout and orientation of the treatment plants (Enplan Group, 1999).

Increasingly, strict legislation, particularly relating to disposal at sea, has resulted in the adoption of BPEO (Best Practicable Environmental Options) approach to the rural and urban planning of sludge disposal.

The availability of GIS has aroused much interest in the planning profession in developing countries in recent years. The ability of the tool to integrate different datasets by relating information by location, so that any one feature of an area can be put alongside its other features, provides the basis for many kinds of spatial analyses.

Planners do need better spatial information; both to foster economic growth and to protect the environment and GIS could improve the planning information base by the creation of a powerful multi-purpose urban information system, which will bring together information from various sources (Goldstein, 1997; Oluwoye, 1998).

In many developing countries, the required database for GIS application to rural and urban planning is either unavailable or incomplete. Much as there is the existence of packages developed to suit the needs of

planners in developed countries, there is the need to study and recommend a procedure for customization of the packages to suit the requirements of developing countries (Adoye, 1998).

The users of GIS software in countries like Nigeria are currently facing serious problems that require researches. Among these problems is that of digital data transfer. For example, the conversion of map data from analogue to digital formats requires the standardization of National Transfer Formats (NTF). NTF is a transfer format for digital map, or spatially related data. This requires that raw data must be coded and classified for example, as to whether the item of data is building, road, contour, land use category or some other. Hence, National Land Use Classification should be laid down in the National Transfer Format.

The study objective of this study is to develop a conceptual framework for site selection disposal of water treatment residuals in developing countries using geographic information systems.

WATER TREATMENT RESIDUALS

Water treatment residuals are a product of the physical and chemical treatment processes that water is subjected to in order to make it potable in line with International drinking water standards. The treatment processes are in turn dependent on raw water quality.

Water from an underground source is generally clear but it may be excessively hard or contain iron and manganese. The soluble salts of calcium and magnesium, which cause hardness and also those of iron and manganese, can be thrown into suspension by chemical reactions and thereafter removal can proceed by settlement and filtration in much the same way as silt can be removed from river water (Smethurst, 1992).

In tropical and subtropical countries climates may be wet as in Nigeria and Brazil, or dry, as in North Africa and the Middle East. Rivers flowing through arid countries are prone to carry very high silt loads and this creates a need for bigger settling basins, which subsequently aids the increase in the yield of residuals (GEO Europe, 1999).

Waterworks residuals consist of relatively clear liquids and /or fairly heavy sludge.

Liquid wastes: Liquid wastes are normally discharged from base-exchange softening plants, which are regenerated with brine. On the average about 6% of the total throughput of the plant is discharged to waste. The main pollutants are the chlorides of calcium and magnesium, in concentrations of about 20, 000 mg L⁻¹.

Such effluents can generally be discharged into town sewers if these exist or into a big river or tidal estuary. They are extremely difficult to treat and where they arise at inland sites in arid countries, care should be taken for disposal to take place under conditions, which preclude any possibility of their polluting surface or underground sources.

Sludge: Sludge can be defined as a highly concentrated suspension of solids in a liquid. In water treatment plants, sludge can be divided into two main types, depending on whether or not it contains chemicals.

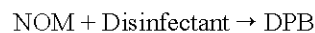
Sludge without chemicals come from plants treating river water and includes those discharged from primary settling tanks, 'roughening' filters, microstrainers and sand washers attached to slow sand filter plants. This type of sludge is relatively inoffensive and can be returned to the river with little treatment or virtually none at all if the river is large.

Sludge containing chemicals are more of a concern as all problems related to sludge collection, treatment and disposal are increased if chemicals are present. This kind of sludge constitutes the major portion of the effluent from a river abstraction plant. The total daily volume of sludge is normally in the range 1.5-5.0% of the daily plant throughput.

The handling and treatment of sludge is a major problem on any works and sometimes receives little consideration by plant designers. Unlike most developing countries, only few river authorities will permit raw or semi-treated sludge to be put back into the river in the developed countries. Federal Environmental Protection laws are however, currently being reviewed in the developing countries to curtail the practice of discharging untreated sludge back into the system (Sonuga and Oloke, 1999).

Disinfection by-products: The application of disinfectants in drinking water treatment for controlling microbial quality has its drawbacks. They include the formation of potentially harmful Disinfection By-Products (DBPs) that can be potential carcinogens (e.g., Trihalomethanes (THMs)) when chlorine, as is very common in most developing countries, is used as disinfectant (Somethurst, 1992).

The general equation is:



Where,

NOM = Natural Organic Matter

Depending on the concentrations of the Total THMs (TTHM) in the DBP, disposal of the residual must either be treated or safely disposed in to large perennial rivers.

Disposal of sludge: There are many methods currently being practiced for sludge disposal in developing countries. These include:

Direct disposal to the river: This is the most satisfactory method if there are no objections by the Environmental Authorities. Its adoption should however be considered only if river flow is large enough and sludge does not contain chemicals.

Discharge into sewers: This is possible in more sophisticated communities which have sewers, discharging the sludge into the sewers is permissible provided that the sludge concentration is within accepted limits usually determined by the Environmental Authorities.

Lagooning: This is a more traditional method of sludge treatment but is far from being trouble-free. As the average depths of water in the lagoons is restricted to only about 1m to allow for effectiveness, very large areas of land are required and even after long periods of storage maximum solids contents of about 10% W/V are rarely exceeded. The end product is very sticky stuff, but can usually be dug and carted away. The volume of sludge retained in lagoons should normally represent about 200 days' effluent from the settling basins. If this averages 2% of daily plant throughput, the sludge stored in lagoons should be about 4 times the average daily plant capacity. In practice such an area is rarely provided and the results are consequently less than satisfactory.

Concentration and drying: Use of concentrating tanks and drying beds are fairly common. The sludge is discharged to secondary fill and draw settling basins. The capacity of each tank would be about 200 m³ in a 10,000 m³ day⁻¹ works and could be scaled up proportionally in bigger works. The sludge has no manurial value but can be used for landfill using the layering methods employed in garbage disposal by municipalities.

Modern techniques: These methods are usually practiced in developing countries and include: Vacuum filtration, centrifuging, freezing and filter-pressing, precipitation softening. They are expensive and should really be avoided when Capital and Operation and Maintenance costs are limiting factors. However, considerations need to be given to them for future planning purposes due

to advantages accruing from some of the procedures. For instance, sludge from precipitation (lime) softening can be treated and the lime recovered provided it does not contain too much silt or coagulant. Lime-softener sludge has certain agricultural merit, as it may be acceptable to the local farmers after it's removal from the drying beds.

GIS APPLICATIONS

A GIS is a computer-based system tool for capturing, manipulating and displaying geographic related data in the computer with specialized software. It is a revolutionary way of integrating the graphical power of maps and the extraordinary wealth of computer databases (Oluwoye, 2002). The database holds data relating to specific objects or areas on the map. The software integrates map and its attribute information in a common spatial database with powerful data management and modeling tools, which allow users to retrieve data, perform sophisticated analysis and output the results as tabular reports or high quality maps (Oluwoye, 1999).

GIS provides a means to integrate graphics, or digital maps, together with textural information relating to a particular location. Depending on the nature of the enquiry that will be made by the user, this means that the GIS can be used to generate reports in graphics or text or both.

The GIS has proved to be a very useful tool in a wide range of applications in many developed countries, especially in organizations such as utilities, central/local governments, mining and petroleum, highways and transportation authorities. It is being used to support day-to-day operation and planning decisions as well as maintenance and administrative tasks of water resources management for monitoring the environment by providing the necessary information where action is needed. It is also being used in planning by providing information on route survey particularly where alternative courses of action can be analyzed. Consequently, developing countries are currently making efforts to incorporate the application of the GIS in various sectors.

Among these applications of GIS in Water Resources Management in particular include 'off-the-shelf' packages that may be procured and customized to meet customer requirements. These include:

- DWDN : Digital Water Distribution Network.
- FARMS : Farm Animal Pollution Risk Management Systems.
- MINDER : Model Input Nutrients, Determine Eutrophication Risk.
- WISDOM : Water Industry Sludge Disposal Optimization Model.

CONCEPTUAL MODEL OF GIS FOR SITE SELECTION FOR DISPOSAL OF WATER TREATMENT RESIDUALS

For the purpose of this study, the WISDOM package or similar are of the most relevant application. The package has been developed for utility customers that are required to develop strategies for the disposal of sewage sludge. WISDOM is a PC-based model that utilizes GIS to assess the agricultural land as disposal resources for sewage sludge. Figure 1 shows the GIS mapping flow diagram.

Procedure: The following procedure shall be adopted within the capabilities of the GIS software to facilitate its customization and optimal output.

- Coding and manipulation of vector or raster data based on the assessment of the developed database to achieve the desired outputs.
- Presentation of data in a continuous format with edge matching.
- Performance of map overlay, map sheet manipulation such as editing and updating features.
- Presentation of reports in both list and tabular formats via a plotter or printer.
- Generation of output in different colors.
- Performance of 3-dimensional terrain modeling for proposed disposal sites.
- Performance of ‘what if’ modeling to allow for changes in legislation, land use, water quality, etc.
- Performance of interactive query and analysis.
- Formulation of guidelines to facilitate application of software and support the inter-disciplinary applications necessary for rural and urban planning.

Development of GIS database and management was shown in Fig. 2.

Selection of case studies: In order to ensure that the outcome of the research addresses the GIS needs of developing countries, the areas to be chosen in Nigeria shall be ensured to reflect both typical urban and rural settings with the incorporation of as many types of raw water sources, treatment works, residual quality and land use.

Database development and management: As many related data that are useful for planning the selection of sites for disposal of water treatment residuals shall be obtained from the study areas. These databases include coverage’s of:

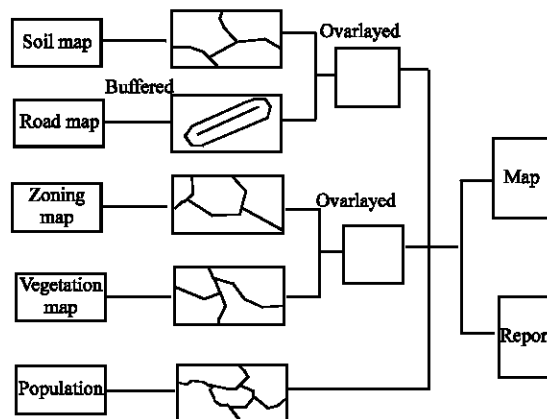


Fig. 1: GIS analysis flow diagram

- Land use
- Demography
- Geology
- Topography
- Drainage system
- Soils
- Vegetation
- Climate
- Infrastructure including water quality/water quality monitoring network and water and waste water works
- Other useful parameters.

As you can from Fig. 2 these coverage’s can be produced in a variety of formats, such as hard copy maps or overlays, or interfaced with an active water quality database (if any) to assist in relating water quality data to spatial data and highlighting water quality and treatment residuals problem areas. Paper-based maps will be converted into digital formats by scanning them using the raster to vector conversion software or by digitizing them in vector format.

The database shall be developed to provide the users with a comprehensive range of query capabilities. It shall be relational in concept maintaining the spatial objects as a reference to feature attributes stored in external Database Management System (DBMS) through an interface provided by vendors. DBMS products currently in the market include VB6, ORACLE, INGRES, INFORMIX, SYBASE, etc.

The chosen DBMS shall be ensured to function with the following capabilities:

- Data definition.
- Data manipulation.
- Provision of security and integrity.
- Enhancement of performance.

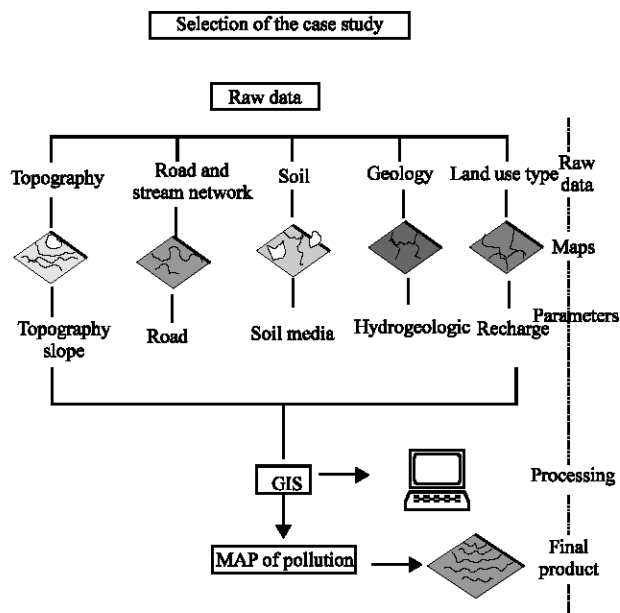


Fig. 2 : Development of GIS database and management

ENVISAGED BENEFITS OF THE CONCEPT

In Fig. 2, the GIS outputs of this concept will aid the institutional strengthening of Urban and Regional Planners in developing countries. The research will among other things:

- Enhance the selection of the most desirable disposal sites of water treatment residuals in developing countries.
- Enable the planners measure levels of derivable benefits and trends of understanding the principles and applications of GIS.
- Examine Urban and Rural Planning developmental studies that will lead to a soundly conceived GIS application programmes.
- Increase the awareness, knowledge and capacity of the potential operators of the GIS for Urban and Regional Planning applications.

In addition to the above, it is also hoped that many areas of future co-operation will be opened up between developing country and the participating developed country in order to tackle future challenges to the operation of the GIS in developing countries. Such areas include:

- Improvement of residual disposal techniques through the application of sludge recycling technologies.
- Supply of relevant GIS software and encouragement of localized software development.
- Training of more citizens personnel in the theory and application of GIS.

CONCLUSION

The proposed framework shall be limited to the acquisition of existing data in raw and digital forms from selected areas of case studies in developing countries.

Existing GIS software shall be procured and customized as part of the research after a database has been designed and formulated from existing data. Masterplans shall be produced for the case study areas for disposal of treatment residuals of existing and proposed treatment works using the appropriate themes developed during the study. Guidelines for the application of the GIS shall thus be formulated and presented. Recommendations shall also be made on areas of future research.

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