Data Warehouse Design for Smart City Applications: A Case Study of Yenagoa City, Bayelsa State

Ebiki Faithful S.[1], Elliot Kizzy N.[2], Okardi Biobele[3], Victor-Ikoh Maudlyn[4]
Department of Computer Science and Informatics,
Federal University Otuoke, Bayelsa State

https://doi.org/10.56201/ijcsmt.vol.12.no11.2026.pg22.31

Abstract
The increase in amount and type of data available as a result of government services, IoT devices, geospatial systems, transportations, security and socio-economic systems create numerous problems related to proper management of such data and decision making based on the evidence in Yenagoa LGA, Bayelsa State. The current study is aimed at investigating the possibility of development of an enterprise Data Warehouse (DWH) for smart city applications in Yenagoa LGA. The research will provide a comprehensive system for the collection, processing, and analysis of diverse urban data. The suggested approach implies utilization of Extract, Transform, and Load (ETL) process for data collection, cleaning, transformation, and integration from the geospatial land registry, real-time IoT hydrological sensors, traffic feeds, CCTV security system, and socio-economic systems. The DWH is designed to be able to support multidimensional analysis, dashboards, reporting, and decision making related to such smart city applications as flood prediction/early warning system, traffic optimization, public safety, environmental monitoring, land-use planning and infrastructure management. Additionally, the implementation issues in relation to the Niger Delta, like flooding, lack of reliable power and network infrastructures, data fragmentation, interoperability, data quality, cybersecurity, and technical capacity issues, will be considered. The proposed framework offers an extensible basis for integration of GIS, AI, cloud computing, and IoT, alongside better data governance and institutional collaboration. The paper ends with policy recommendations towards sustainable implementation of the framework, stressing the development of infrastructure, standards for data sharing, security, capacity building, and phased adoption. It is anticipated that the proposed DWH will contribute to data-driven governance, prediction of decisions, resource allocation, public service delivery, and smart cities development in Yenagoa LGA.

Introduction & Background

The Urban Evolution of Yenagoa

Recent researches define smart cities as urban settings where use of digital technology, IoT, connectivity, and data analytics help to enhance governance, service delivery, sustainability, and urban quality of life (Bibri, 2019; Stübinger & Schneider, 2020). The city of Yenagoa, which is the capital city of Bayelsa State and one of the largest urban centers in the Niger Delta, is witnessing rapid urbanization in a low-lying terrain comprising wetlands, swamps, creeks, and rivers. Urbanization in Yenagoa has created increasing pressure on transportation systems, drainage systems, waste management, land use control, environmental management, and

infrastructure systems. With the increasing availability of data from sources like IoT sensors, GIS, CCTV, and other digital devices, there is an opportunity for enhanced urban monitoring and planning but the integration of this heterogeneous data becomes crucial for making informed decisions (Lau et al., 2019; Soomro et al., 2019).

The Problem of Data Silos in Yenagoa

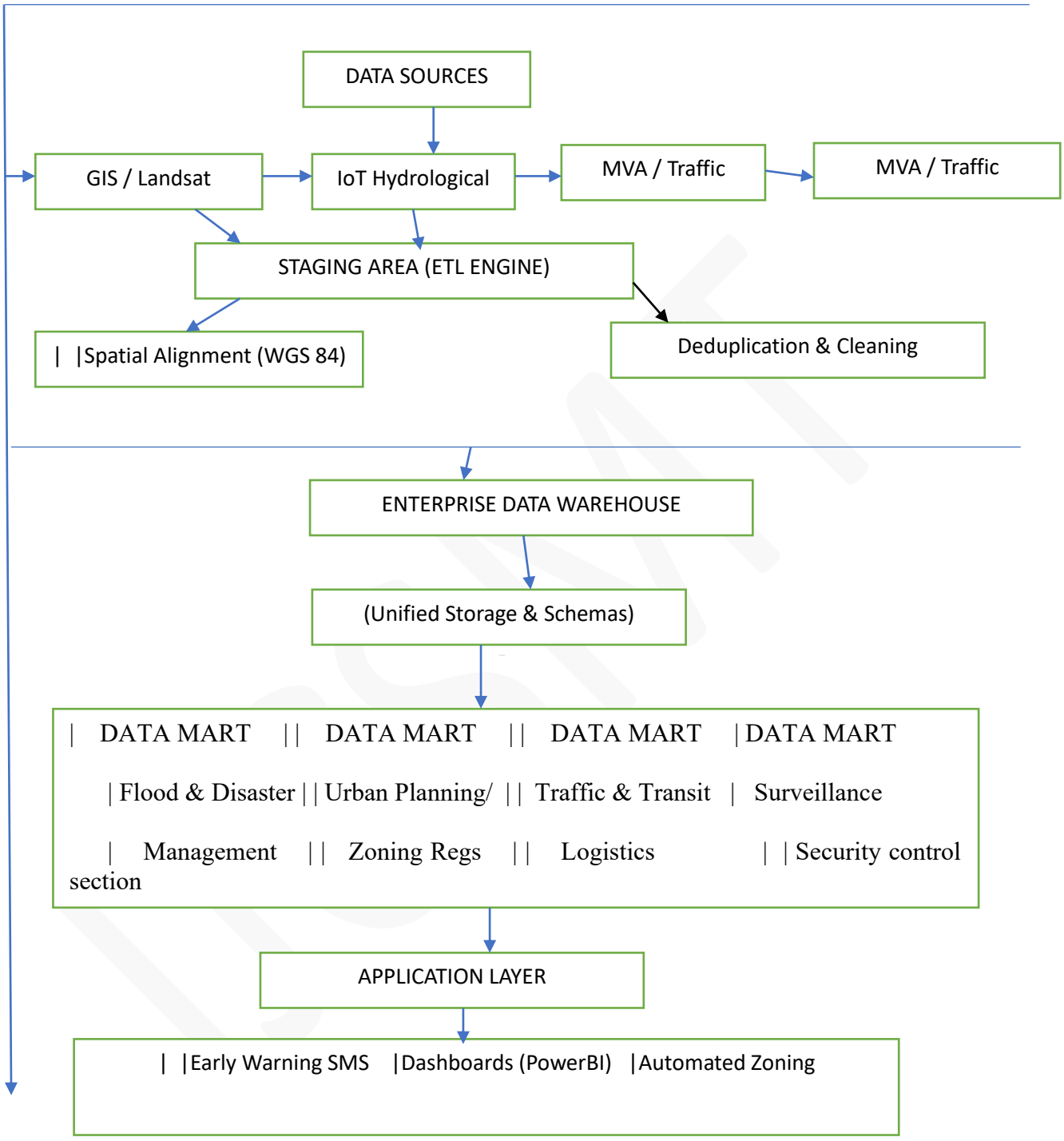
One of the issues being faced in the field of urban planning and management in Yenagoa is the fragmentation of data in areas like land administration, transportation, physical planning, environment, security, and emergency. In other words, there is data about land allocation, building permits, flood levels, traffic conditions, infrastructure, and socio-economic activities that are scattered across different systems without proper mechanisms for data integration. Such situations may lead to poor decision-making and poor response of the authorities to urban issues. There are numerous findings in recent studies on smart cities that indicate integration of data from various heterogeneous data sources is very important for intelligent urban services and decision-making (Lau et al., 2019; Hajjaji et al., 2021). Moreover, it is required due to the volume, variety, velocity, and complexity of data used in smart cities (Karimi & Mahdipour, 2021). Thus, it becomes evident that there should be an integrated Data Warehouse (DWH) system in Yenagoa.

The Smart City Paradigm and Data Warehousing

Smart cities use IT, IoT, GIS, and data analytics in order to enhance the efficiency of urban services, governance, sustainability, and decision making (Karimi & Mahdipour, 2021; Ullah et al., 2023). The Data Warehouse (DWH) serves as a unified platform for the integration of different urban data and enables the analysis of the past, creation of dashboards, reports, predictive models, and decision-making (Lau et al., 2019; Soomro et al., 2019). In case of Yenagoa LGA, the DWH will help to integrate data on land and GIS, hydrological sensors, traffic, CCTV, infrastructure, and socio-economic data in order to be used in the processes of flood prediction, traffic control, security, and planning of the city.

Architectural Blueprint of the Smart City Data Warehouse

The suggested DWH will need a tiered architecture that will be able to manage the integration of both spatial and non-spatial data. It is made up of data sources, ETL / Integration, data warehouse storage, analytics, and presentation tiers. Data are gathered from GIS/land information, IoT sensors, traffic management system, CCTV, government information, and socio-economic information; ETL then cleans, transforms, validates and loads the data into the centralized data warehouse. The data warehouse is designed for historical analysis and multi-dimensional analysis, whereas the analytics and presentation tiers include dashboards, GIS mapping, reporting, alerting, and decision-support systems.



2.1 Data Acquisition & Source Layers

Data is extracted from four major layers of the Yenagoa city metropolitan from the DWH, namely:

i. Geospatial and Environmental Layer: These include satellite imagery (Landsat/Copernicus), DEMs and shape files for the location and path of Epie Creek and Nun River.

ii. IoT Sensor Network: The telemetric information from water-level radar sensors placed in

flood-vulnerable locations (for example, Swali, Tombia, Polaku and Kpansia, Agudama, Okolobiri, Elebele, Opolo, Okaka, Igbogene etc.

iii. Infrastructure and Transport Logs: This includes GPS logs from the public transportation networks, traffic density from the Mbiama-Yenagoa corridor and metrics from the new layout of Yenagoa City.

iv. Special security/CCTV control department (army, navy air force DSS, police, civil defence bayelsa safety corpse and Bayelsa State vigilantee). etc.

v. Administrative and socio-economic Layer: NPC demographic statistics, municipal taxation frameworks from Bayelsa State Internal Revenue Service (BYIRS) and health data from Bayelsa (PHC) Data Hub

2.2 Staging and ETL (Extract, Transform, Load) Processes

The data reaching the staging zone is highly unstructured and volatile. There are a number of important processes that happen within the ETL process:

i. Spatial normalization of data: Converting different spatial coordinates to one single standard, like WGS 84/UTM zone 32N to have exact positioning.

ii. Data cleansing: Resolving the conflict between street names found in historical data from various municipalities and those from BSPPDB structure approval records.

iii. Temporal synchronization of high frequency IoT streaming telemetry data (sec/minute) with low frequency administrative records (monthly).

2.3 Storage and Data Mart Design

In terms of core storage, it makes use of Star Schema design, which is based on the fact table that is central and connected to descriptive dimensions. In order to improve the efficiency of queries in case of different municipal bodies, the central warehouse is divided into specific Data Marts:

i. Flood and Disaster Management Mart: This mart includes dimensional information on rainfall, low-lying elevation and vulnerability index.

ii. Urban Planning and Zoning Mart: This mart includes historical data on land parcels, violations and buffer zones.

iii. Special Security/CCTV Control Department.

iv. Traffic and Transit Mart: This mart is devoted to the evaluation of commuting time and road friction points.

3. Targeted Smart City Application Modules for Yenagoa

3.1 Smart Flood Predictive System

As Yenagoa is prone to seasonal flooding caused by river and pluvial sources, the DWH incorporates historical rainfall data together with current data about telemetric water levels. Machine learning models will be able to make predictions on when the flooding will occur through calculating real up water level using DEM stored in the data warehouse. This data can then be used to send SMS-based alerts to vulnerable riverine communities such as Obogoro and Agbura through the automated early warning system.

3.2 Traffic Optimization & Transit Network Analysis.



Fig. **1: pictures of traffic light.**

Yenagoa's reliance on a single transport corridor poses serious traffic bottlenecks in the peak period. There is a traffic analytics application linked with the DWH that processes information about congestion measurements and public transport facilities' positions. With spatial network analysis, urban planners can construct mathematical models of shortest paths as well as create routes for fire trucks and medical vehicles through emergency response optimization. Furthermore, there is a possibility to calculate spatial buffers and define bus stops at the recently developed Glory Drive.



Fig 2. Pictures of Ultra Modern Motor park

3.3 Spatio-Temporal Growth Modeling & Zoning Enforcement

Monitoring structural approvals through comparing approved structures from the building approval process with images of satellite structures recently inputted into the DWH can help determine the existence of structures which have not been approved. This will assist the Bayelsa State Physical Planning and Development Board in preventing the emergence of slums and maintaining drainage routes.





Fig 3. Pictures of Infrastructures.





3.4 Special Security/CCTV camera control department. By installing Special Security/CCTV control Department to check mate crime control, this will make the city safer





Fig 4: Pictures of Surveillance/ CCTV camera

3.5 Constant Electricity/Gas Turbine.

Yenagoa, a fast-growing city that relies on NEPA a few years back, has begun experiencing 18 hours power supply in parts of the city such as oxbow lake, Kpansian, Opolo, Okaka among others owing to the introduction of gas turbine by NLCDB. The state government under the leadership of His Excellency Sen. Douye Diri in its quest for development has introduced state government gas turbine that will provide 24 hours power to Yenagoa. Another development is the installation of solar-powered street lights in Yenagoa by the state government, NLCDB and NDDC that is making Yenagoa a city.



Fig 5. Pictures of Gas Turning, Solar powered light.

3.6 The Construction of Roads Across Yenagoa

Several roads constructed by both State Government and NDDC is gradually turning Yenagoa to a transformer City called Smart City.



Fig 6. Network of Roads.

4. Implementation Challenges in the Niger Delta Context

i. **i. Infrastructural and Energy Shortfalls:** The steady input of data into a Data Warehouse demands steady power supply and high-speed data networks. Power outages and unreliable telecommunication systems are problems in the Niger Delta that pose obstacles.

ii. **ii. Bureaucratic Hurdles Regarding Data Sharing:** Institutional rigidity and the lack of open data laws between MDAs can be a hindrance in sharing of data, keeping vital information within individual ministries.

iii. **iii. Technological Expertise Shortfalls:** Expert skills are needed to manage enterprise ETL processes, spatial data extensions, and data warehouses. There is a shortage of engineering skills in Yenagoa when it comes to data architecture and spatial analysis.

5. Conclusion & Policy Recommendations

The transition of Yenagoa into a working smart city needs to shift away from a segmented data storage process. The establishment of a centralized Data Warehouse provides an analytical base for data-driven flood management, logistics, and urban planning.

For this, the following Recommendations should be put in place:

i. Implement a Data Governance Policy: Formulate state-level regulatory policies that compel all municipal MDAs to feed normalized datasets into a secure centralized repository.

ii. Set up a Hybrid Cloud Computing Infrastructure: Implement localized secure servers for managing identity information alongside scalable cloud environments that will enable heavy spatial and predictive computations.

iii. Take up the Incremental Phased Approach: Roll out the data warehouse program by starting with the Flood Management and Urban Zoning data marts first, which will offer quick results before going all out to implement the whole municipal system.

iv. Use Computerized surveillance systems within the DWH with CCTV Cameras installed in order to monitor the influx of persons and cars into the Yenagoa LGA.

v. Use Computerized traffic control system within the DWH with CCTV Cameras installed across the city.

References

Bibri, S. E. (2019). The anatomy of the data-driven smart sustainable city: Instrumentation, datafication, computerization and related applications. *Journal of Big Data, 6*, 59. https://doi.org/10.1186/s40537-019-0221-4

Hajjaji, Y., Boulila, W., Farah, I. R., Romdhani, I., & Hussain, A. (2021). Big data and IoT-based applications in smart environments: A systematic review. *Computer Science Review, 39*, 100318. https://doi.org/10.1016/j.cosrev.2020.100318

Karimi, M. A., & Mahdipour, E. (2021). Leveraging big data in smart cities: A systematic review. *Concurrency and Computation: Practice and Experience*. https://doi.org/10.1002/cpe.6379

Lau, B. P. L., Marakkalage, S. H., Zhou, Y., Ul Hassan, N., Yuen, C., Zhang, M., & Tan, U.-X. (2019). A survey of data fusion in smart city applications. *Information Fusion, 52*, 357–374. https://doi.org/10.1016/j.inffus.2019.05.004

Soomro, K., Bhutta, M. N. M., Khan, Z., & Tahir, M. A. (2019). Smart city big data analytics: An advanced review. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 9*(5), e1319. https://doi.org/10.1002/widm.1319

Stübinger, J., & Schneider, L. (2020). Understanding smart city—A data-driven literature review. *Sustainability, 12*(20), 8460. https://doi.org/10.3390/su12208460

Ullah, A., Anwar, S. M., Li, J., & Nadeem, L. (2023). Smart cities: The role of Internet of Things and machine learning in realizing a data-centric smart environment. *Complex & Intelligent Systems, 10*, 1607–1637. https://doi.org/10.1007/s40747-023-01175-4 *pipelines, and integrated data health systems*. Technical Report, CMS Platforms.

Elangovan, K., & Krishnaraaju, J. (2023). Multi-criteria evaluation and cellular automata models for predicting urban development patterns. *Environmental Monitoring and Assessment*, 195(2), 310–326.

Ershad, M., & Ali, A. (2020). Database design considerations for integrating GIS data with enterprise data warehouses. *Computers, Environment and Urban Systems*, 82, 101–115.

Giffinger, R., et al. (2007). *Smart cities: Ranking of European medium-sized cities*. Centre of Regional Science, Vienna University of Technology.

Infield, J. A., & Ifeka, A. C. (2020). Assessing the impact of seasonal flooding on the socio-economic infrastructure of Yenagoa city. *Nigerian Geographical Journal*, 16(2), 89–104.

Irfan, M. (2005). *Urban road network analysis using geographic information systems*. Springer-Verlag.

Kim, R., & Ross, L. (2013). *The Data Warehouse Toolkit: The definitive guide to dimensional modeling* (3rd ed.). John Wiley & Sons.

Mehari, G., & Genovese, P. V. (2023). Systematic spatial planning integrating environmental and socio-economic goals. *Sustainability*, 15(7), 5890.

Mehra, S., & Swain, P. C. (2024). Spatio-temporal mapping of land use and land cover (LULC) changes using cloud-based remote sensing. *Geo-spatial Information Science*, 27(1), 64–78.

National Population Commission (NPC). (2010). *Federal Republic of Nigeria 2006 population census official report*. NPC, Abuja.

Nte-Alagoa, E., & Tari, T. (2022). Change detection analysis in Yenagoa due to urbanization using remote sensing and geographic information systems. *World Journal of Advanced Research and Reviews*, 15(1), 439–446.

Nwilo, P. C., et al. (2019). Flood vulnerability mapping in the Niger Delta basin using GIS and

remote sensing techniques. *Journal of Hydrology: Regional Studies*, 24, 100–115.

Odubo, T. R. (2015). *Urban road network analysis of Yenagoa, Bayelsa State using GIS*. (Master's thesis, University of Port Harcourt). ResearchGate Publication.

Okoko, E. (2006). *Quantitative techniques in urban analysis*. Kraft Books Limited.

Olubi, O., & Fadamiro, J. (2022). Challenges of rapid urbanization on infrastructural sustainability in southern Nigeria. *Journal of Urban Systems and Development*, 8(2), 143–158.

Oyinloye, R. O., & Oloukoi, J. (2018). Urban growth modeling of rapidly growing state capitals in Nigeria using geospatial technologies. *African Spatial Science Review*, 11(3), 12–33

Rathore, M. M., et al. (2016). Urban big data analytics for smart cities in a cloud environment. *Journal of Networks and Computer Applications*, 69, 104–119.

Reddy, P. R. (2018). *Textbook of remote sensing and geographical information systems* (5th ed.). BS Publications.

Rocha, J., et al. (2023). GIS buffer and overlay operations in analyzing municipal infrastructural gaps. *Transactions in GIS*, 27(3), 745–762.

Single, S., & Malik, H. (2021). ETL engine architectures for handling real-time IoT sensor telemetry streams in smart environments. *IEEE Access*, 9, 13450–13462.

Tokula, M. A. (2021). Data warehouse frameworks for municipal authorities in developing nations: Operational challenges and benefits. *Journal of Enterprise Information Management*, 34(5), 1201–1218.

Unah, P., & Okopi, A. (2021). Rural-urban migration and the physical expansion of secondary cities in Nigeria. *Journal of Sustainable Development in Africa*, 23(1), 45–60.

Weli, V. E., & Ifeka, A. C. (2018). Analysis of rainfall trends and flooding anomalies in Yenagoa, Bayelsa State, Nigeria. *International Journal of Atmospheric Sciences*, 2018, 1–11.

Xhafa, F., & Kosovrasti, A. (2015). Combining spatial data with analytical enterprise platforms for urban decision making. *Journal of Systems Architecture*, 61(10), 567–578.

Jung Noon et al. 2013 international Journal, Urban Science, 17(3), 253-266

Nam and Pardon, (2011) international Journal Urban Technology, 18(3), 109-127

Barbara et.al (2013) International Journal Technological Forcasting and social change 120, 3-14 Vol. 120.

Zanella et al. (2014) International Journal, IEEE Internet of Things (IoT)101, 22-32.