Journal of Environmental Science and Management 7(1):1-9 (June 2004)
ISSN 0119-1144

Visualizing Sea Level Rise in Navotas by GIS and Terrain Modeling

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Abstract

Flooding due to sea level rise is a primary concern brought about by climate change. This study focuses on northern Navotas, Metro Manila, a densely populated urban area affected by frequent diurnal changes in sea level. The study verifies terrain data vis-a-vis its vulnerability to water level rise using Geographic Information System (GIS) and 3D Terrain Modeling-Visualization software. The research introduces a method to evaluate vulnerability and predict how such change in sea level will spatially affect a certain locality. The primary objective is to provide a three-dimensional visualization technique that will integrate geospatial data with possible changes in sea level. Topographic information is linked with planimetric data from existing maps and aerial photography. Visualizations of several levels of increase, at 0.25-meter intervals are presented, with political boundary overlays, selected buildings and aerial images. Results are then compared with demographic data, and affected population is deduced. Based on one simulation result, about 96.49 hectares within the 200-hectare study area will be affected by a 1-meter rise in sea level, with 54,145 individuals affected. Limited ground truthing during a high tide event verified some of the predicted submergence along the main roads. The high-resolution simulation presented by the study provides an effective means to visually and spatially assess the extent of topographic vulnerabilities of a locality to possible sea level change, and may help communities plan effectively for such events.

Key words: *sea level rise, terrain modeling, Geographic Information System (GIS)*

INTRODUCTION

The subject of climate change through global warming presents numerous complexities in the way the environment responds; one notable area is through changing the global equipotential surface, the mean sea level. The main reasons for possible Sea Level Rise (SLR) considered in this study are unmitigated carbon dioxide emissions due to anthropogenic activities, as well as natural geodynamic processes, such as eustatic elements (glacier melting) and isostatic factors (crustal rebound). The US Environmental Protection Agency (EPA) approximates that there will be a 1% chance of a global 1-meter SLR by year 2100 and 50% chance of the same by 2200 *(Eastman and Gold 1996)*. The Hadley Center predicts that by 2080, there will be a 41-centimeter global rise (using the 1961-90 baseline) for unmitigated carbon scenario *(Nicholls 1999)* **(Table 1)**.

Based on the study of Nicholls *(1999)*, flood impacts of SLR by year 2080 will be greatest in South Asia (including Pakistan, Bangladesh, Sri Lanka, India, and Myanmar) and in Southeast Asia (including the Philippines, Thailand, Indonesia, Malaysia, and Vietnam). A 30-centimeter rise (750 ppm scenario) will affect 34 million people, while a 27-centimeter rise will affect 19 million individuals.

This study integrates the use of 3D visualization tools and Geographic Information Systems (GIS) in the assessment of vulnerability to sea-level rise (SLR) and the exact location of areas which will be submerged under water. The main objective is to provide a method which can integrate existing spatio-demographic datasets and present comprehensive mapping information to users who need to plan and evaluate certain related scenarios. The focus would be mainly methodological, since the primary limitation of

Table 1. Global sea level rise projections due to climate change for mitigated and unmitigated scenarios for 2080 and 2230

SCENARIO	2080	2230
Unmitigated	41 cm	
750 mm	30	94
550 mm	27	75

Source: The Hadley Center c.f. Nicholls 1999

the study is the availabilty of more recent topographic data.

Visualization tools present information as images. These are valuable in urban planning activities and in the evaluation of land use policies. Specifically, planners and decision-makers are able to model scenarios by tracing occurrences through simulations *(Thumerer 2000; Titus 2001).* In this case, Geographic Information System was used in tandem with a 3D visualization software to highlight flooding scenarios, and pinpoint affected areas at the barangay level.

Study Area

Navotas is among the four municipalities and 11 cities, which comprise the National Capital Region or Metro Manila, Philippines. It has a population of 230,403 (based on year 2000 data), and ground elevations ranging from 0 to about 3 meters above mean sea level (amsl). It is bounded in the north by Bulacan, in the northeast and east by Malabon, and in the south by Manila. It is among the most densely populated municipalities in Metro Manila, with 692.3 persons per square kilometer. Industrial areas such as warehouses, shipyards, and some factories are mostly located along river banks, near the waterlines, while residential and institutional areas comprise majority of the areas at the center of the island.

Navotas, along with the municipality of Malabon and cities of Caloocan and Valenzuela, experiences frequent flooding due to typhoons, and even during the occurrence of high tides. The focus of the study is the northern island, which contains several barangays: Tangos, San Roque, Daang Hari, San Jose, Navotas West, Navotas East, Bagumbayan North and South *(Navotas MPDO 1999).* The range of elevation on the island is approximately 0 to 2 meters amsl, with an area of about 200 hectares.

The topographic details and location of the study area were derived from the National Mapping and Resource Information Authority-Japan International Cooperation Agency (NAMRIA- JICA) 1:10,000 Topographic Map. The location is between 120°55'30" E to 120°57'00"E longitudes and 14°39'00" N to 14°41'00" N latitudes. This map was scan-digitized and converted to gridding formats. Gridding formats are specifically used to generate interpolation framework for the determination of ground elevations. The population affected by such flooding (after 1.0 m and 1.5 m sea level rise) is mapped out per barangay. Software used for image processing was ERMAPPER 6.0 (a Software Product of Earth Resource Mapping, Pty., Australia); IDRISI GIS for Geographic Analyses (Clark Labs, Inc. of Clarke University in Massachusetts, USA); and GeoView-3D for 3D Visualization and Analyses (3-Dimensional GIS and Modeling software developed by GeoAnalytika Technical and Engineering Consultancy, Philippines).

METHODOLOGY

Digital Elevation Models (DEM) or Digital Terrain Models (DTM) are simple digital representations of topography. These are frequently based on raster grids defined in the x, y, and z or elevation coordinates (*NCGIA 1993*). DEMs can be used to determine terrain characteristics and attributes, such as point elevations, slope, and aspect. Likewise, terrain features such as drainage basins, waterways, watersheds, drainage networks, and channels, and other land features can be located. Subsequent scenarios can be modeled using DEMs.

The entire process of building a 3D terrain model and 2D GIS database involved the use of various data, software and hardware implements. For example, the topographic map was used as reference, ERMAPPER was used for image processing, and GeoView-3D for terrain modeling and time series display. Triangulated Irregular Network (TIN) models were used to generate the DEM, where triangles define surface features, with their vertices derived from spot elevations.

In particular, the NAMRIA-JICA 1:10,000 topographic map was scan-digitized to provide the basemap. The said map (produced in 1987 under the NAMRIA-JICA project) is based on the Universal Transverse Mercator Projection, Zone 51, with the Clarke Spheroid of 1866 as reference datum. Vertical datum for topographic elevations was referred to Mean Sea Level (MSL) for heights above water, while bathymetric depths were based on Mean Lower Low Water (MLLW) *(NAMRIA-JICA 1998)*.

GIS data were derived from this scanned map. These include planimetry, contour levels, spot elevations, and bathymetry as well as some land use/ land cover features. Vector maps of various layers based on these were imported into IDRISI and were transformed to several thematic layers such as elevation, planimetry, and land cover. Additional Administrative Boundary (Barangay-level) data were likewise imported into the system *(NCTS-MMUTIS 2000)* **(Figures 1 and 2).**

RESULTS AND DISCUSSION

From these data sets and GIS layers, analysis was done using mathematical combinations between layers, or by overlaying various themes. For 3-dimensional modeling, surface interpolation was done through GeoView-3D, using the Triangulated Irregular Network (TIN) Model **(Figure 3)**. This produced the 3D model of the Navotas main island, including high points and bathymetry. Footprints of major buildings were likewise digitized and projected into 3D space. This is for enhanced displays and also to determine major structures affected by SLR.

Scanned image maps were also overlaid to the resulting terrain model, making them more realistic in appearance, reflecting additional cartographic and spectral details. **Figure 4** shows the rectified aerial photo image overlaid on the DEM. SLR in increments of 0.25 m, simulated up to 1.75 m, was made by altering the color palette, classifying elevation values as either above or below water level mark. From this, a time series model was done under GeoView-3D, and was exported to MPEG/AVI format. The terrain model could also be used to generate slope and aspect maps, which are helpful in determining water flows and hydrology.

After simulating a 1-meter increase in sea level with other variables, such as Barangay boundaries/ areas, and population being constant at year 2000 levels, affected areas and population were obtained **(Table 2)**. For a total of 200 hectares, 103.51 hectares (51.8%) will remain above water after an increase of 1 meter in sea level, submerging 96.49 (48.2%) hectares of mostly high-density residential lands. Population-wise, based on the projected year 2000 data *(Navotas MPDO 1999)*, the entire affected population in the study area would be 63,808 out of a total of 133,404 or 47.8%. This approximation, however, is area-based as it assumes constant population density per area of land, regardless of land use.

The most heavily affected barangays in the island would be Tangos (14. 81 ha of land affected and 15,124 out of 31,663 individuals) and San Jose (38.99 ha of land and 12,621 out of 22,983 individuals). The least affected would be Bagumbayan South (3.61 ha and 2,713 out of 3,754 individuals) and Navotas East (2.49 ha and 931 out of 2,248 individuals). **Figure 5** shows the aerial photo-DEM visualization with a 1-meter SLR, while **Figure 6** shows the administrative map in plan view with the same 1-meter SLR. Both images indicate considerable area affected by water.

Limited ground truthing conducted by the Manila Observatory team during a high tide event in August 2001 verified that predicted submergence of certain parts along the main roads did occur, at about 1.8 meter diurnal increase in sea level **(Figure 7)**. Likewise, the presence of high-density, blighted areas along coastal regions were notably within the submerged zones **(Figure 8)**.

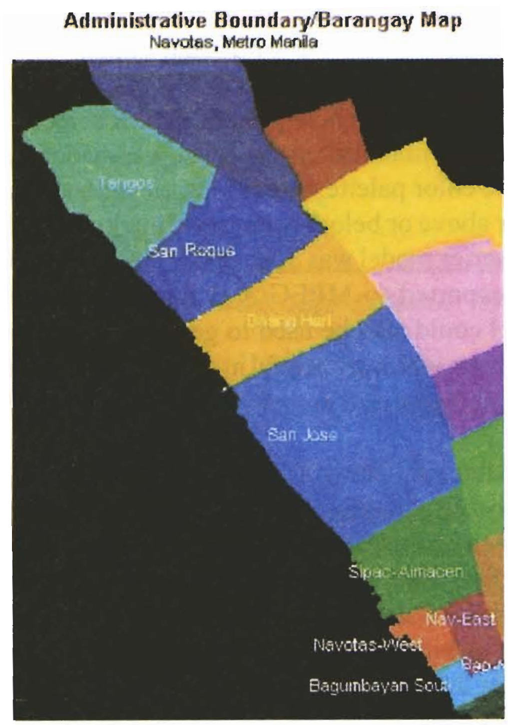

Fig. 1. IDRISI GIS map of Navotas administrative boundaries (selected Barangays at 0 m sea level)

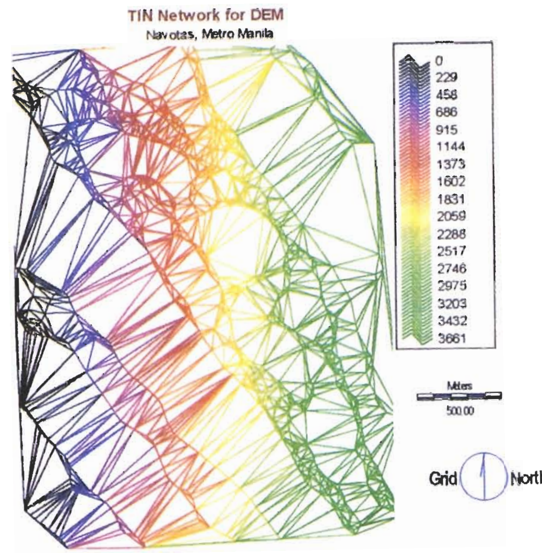

Fig. 3. Development of TIN Network, with various weights depicted in colors (This is the basis for determining the 3D elevation model.)

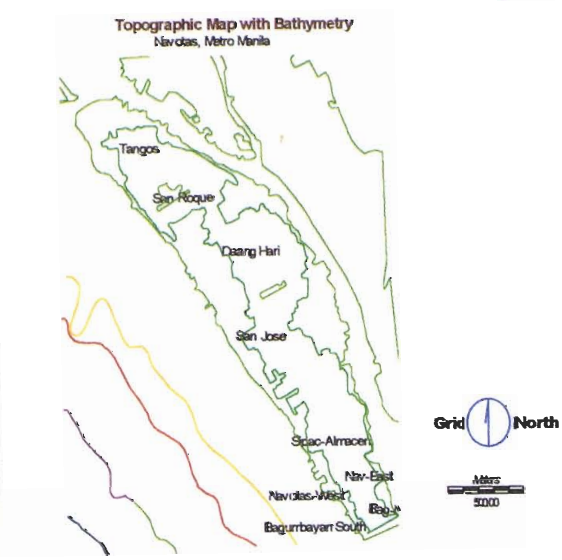

Fig. 2. Topographic map of Navotas showing contours at various elevations (Source of digitized data is the 1988 NAMRIA-JICA land use map.)

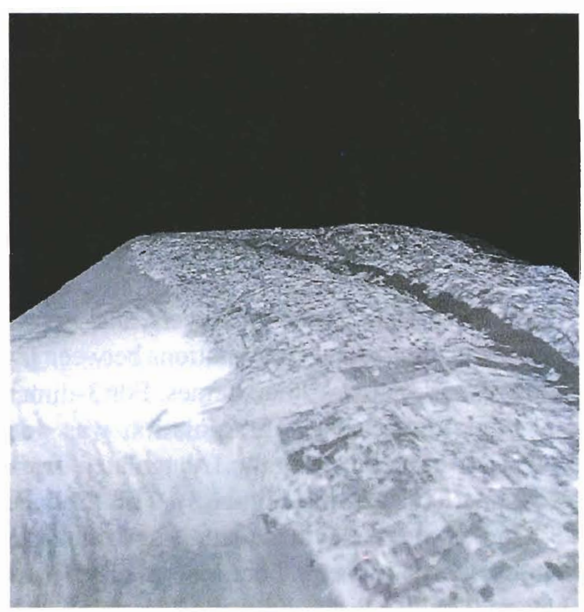

Fig. 4. 3-Dimensional Model of Navotas with aerial photography (1996) overlaid on the TIN Model in isometric view (Depicted is actual scene at 0 m sea level rise.)

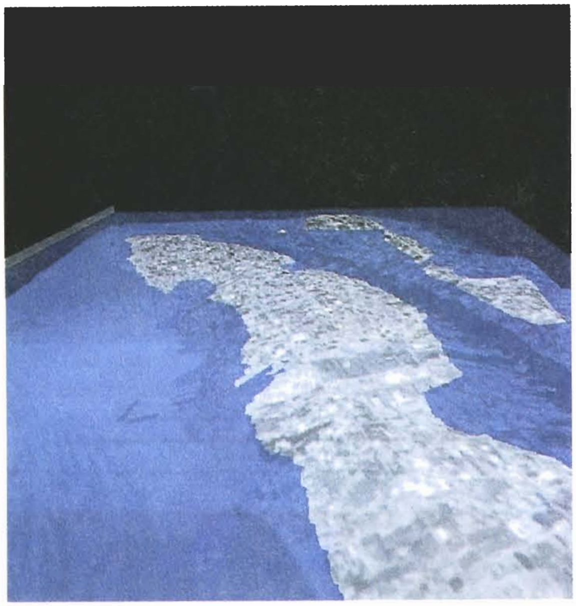

Fig. 5. Isometric view of the 3-Dimensional Model of Navotas, after significant SLR (This scenario shows 1 m sea level rise. Flooded areas are shown in blue.)

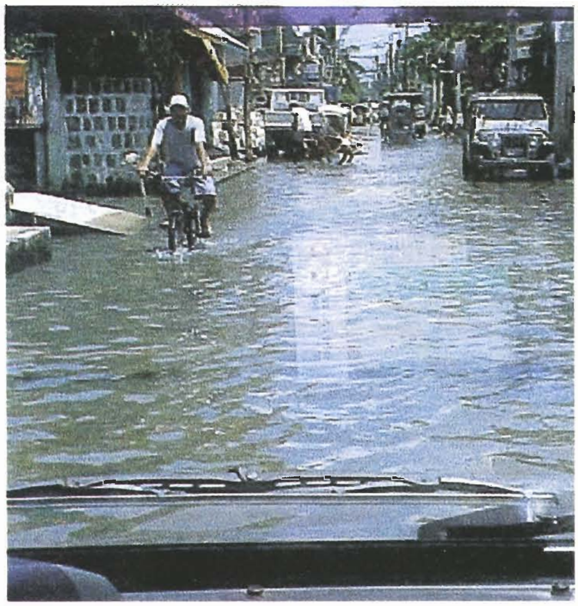

Fig. 7. Ground truthing photographs made in August 2001, at exactly 1.8 meter (from MLLW) tidal rise (Image shows flooded main street in the same area.)

Fig. 6. IDRISI GIS map of Navotas administrative boundaries after 1m sea level rise

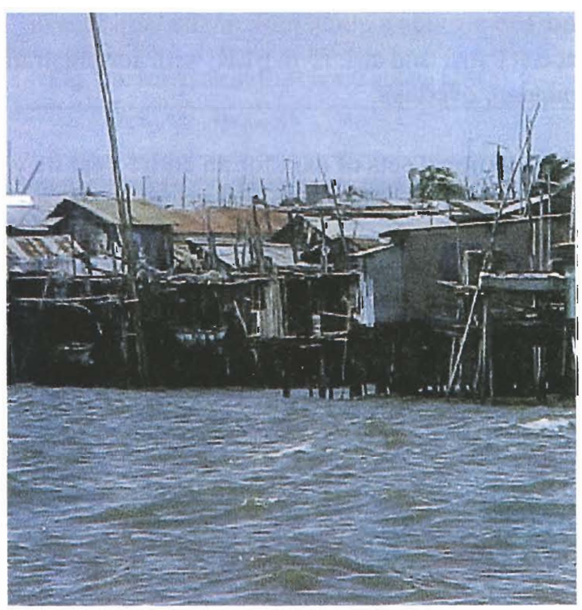

Fig. 8. Ground truthing photographs reveal perilous existence of houses on stilts (shanties) which were erected off the coast in the study area

Table 2. Population of barangays in Navotas in years 1995 and 2000 and affected population by 1-meter SLR

BARANGAY NAME	AREA OF BRGY. (ha)	REMAINING AREA AFTER 1- mSLR	AFFECTED AREA BY 1- mSLR	POP'N. 1995	POP'N. 2000 (NSO Census)	AFFECTED POP'N. BY 1-mSLR (based on 2000)
Tangos	31.00	16.19	14.81	29,497	31,663	15,124
San Jose	71.00	32.01	38.99	22,558	22,983	12,621
Daang Hari	26.00	17.03	8.97	14,692	17,678	7,754
San Roque	27.00	15.16	11.84	21,117	16,274	5,616
Sipac-Almacen	27.00	15.23	11.77	8,191	11,232	4,897
Navotas-West	7.00	3.00	4.00	7,210	7,851	4,489
Bagumbayan South	5.00	1.39	3.61	4,397	3,754	2,713
Navotas-East	6.00	3.51	2.49	2,929	2,248	931
Total	**200.00**	**103.51**	**96.49**	**110,591**	**113,683**	**54,145**

Sea level rise at 0 m, 0.25 m, 0.5 m , 0.75 m., 1.0 m., 1.25m. and 1.75 m were also simulated by thresholding the elevation data set, in effect simulating water level rise. The resulting SLR elevation maps overlain with the barangay boundary and population data gave detailed information on which barangays will be submerged under water at certain levels. The affected population were derived from these overlays. **Figures 9a to 9f** show visualizations of incremental rise, emphasizing the rapid decrease in land area as sea level rise progresses. Meanwhile, **Figures 10a and 10b** provide a quick look on the land area difference at 0 msl and at 1.75 m SLR, with administrative boundary overlays.

Additional sets of data for an entire year may be acquired and could be used to model seasonal and monthly variations in sea level (or high tide level), and to match affected areas with the existing population distribution. This will further refine the mapping process, and provide accurate variations in the affected areas.

CONCLUSION AND RECOMMENDATIONS

The study shows high vulnerability of Navotas with respect to sea level rise, based on terrain information alone. Furthermore, the images present specific areas that will be affected by incremental rise in water level, and enabled deriving equivalent affected population on a per area basis. The visualizations derived can likewise describe present-day tidal flooding (diurnal cycles), which normally reaches 1.8-2.0 masl during rainy season.

3D simulations and GIS applications aid in viewing future scenarios and impacts of sea level rise, thereby constituting an important set of tools for the government, urban planners, and decision makers. For instance, flood control project planning may be aided by locating the exact area affected, and during post-planning (or even post-construction), effectivity of such structures may be evaluated electronically. Likewise, during inundation and emergency situations, pinpointing accurately would-be affected residential areas will greatly increase mobilization capacity of relief and social welfare agencies. The use of GeoView-3D, a 3-D GIS and modelling software, provided adequate support in the creation of simulated scenarios, flythrough animation and multi-view visualization. On the other hand, IDRISI of Clark Labs was utilized to obtain areas affected by flooding.

Several limitations are inherent in the database used. For instance, the type and date of information available are based on the 1988 topographic and land use maps. Based on the ground truthing conducted by the Manila Observatory team in 2001, roads and some structures have been improved and elevated. These new sets of elevation points will create a rather differently interpolated surface model, hence affecting

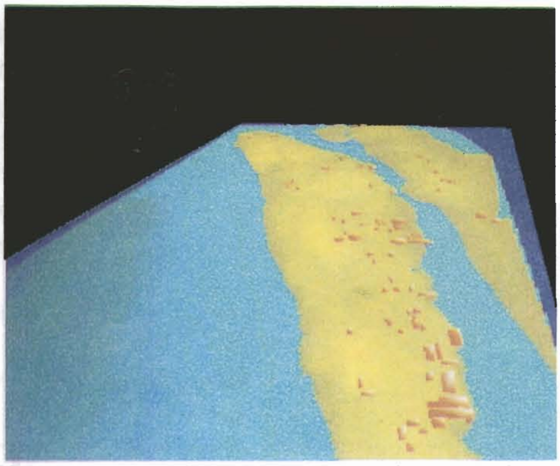

Fig. 9a. 3D view of Navotas at Mean Sea Level (MSL) (blue = water; green = land; red = buildings)

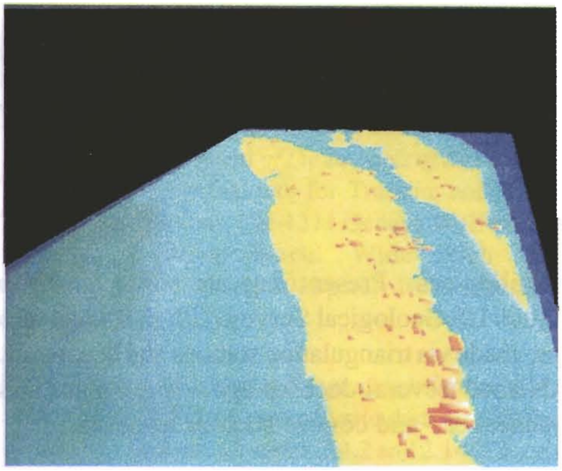

Fig. 9b. Navotas at SLR = 0.25 above MSL

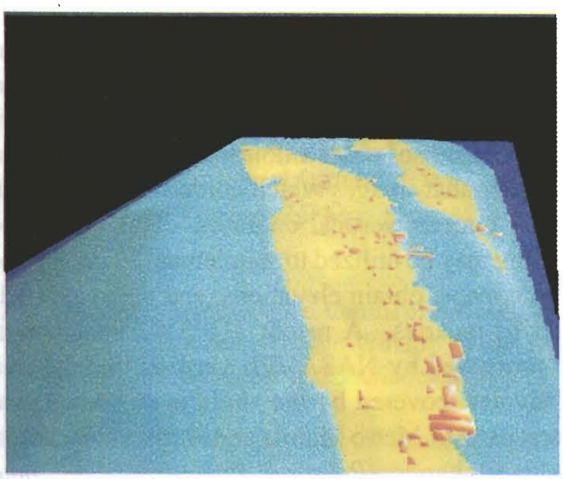

Fig. 9c. Navotas at SLR = 0.5 above MSL

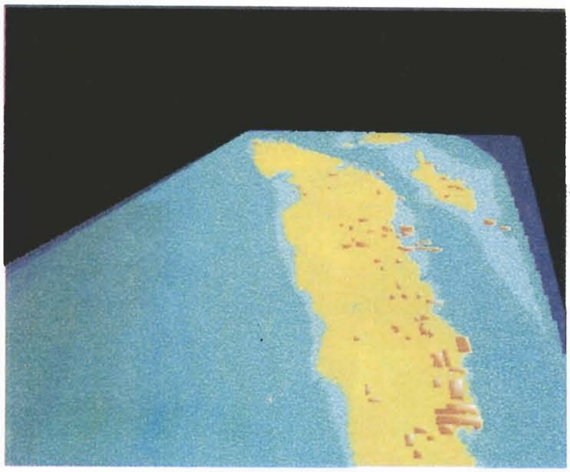

Fig. 9d. Navotas at SLR = 0.75 above MSL

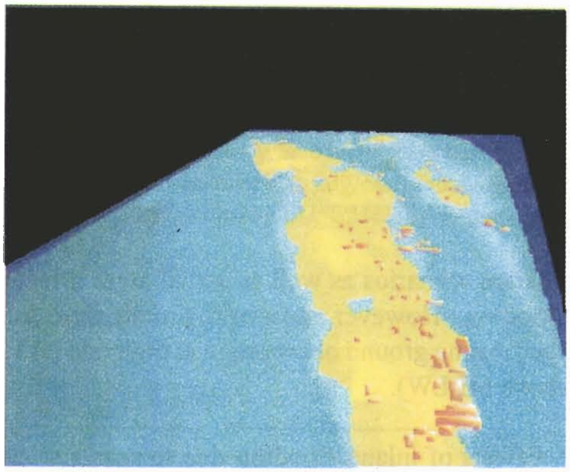

Fig. 9e. Navotas at SLR = 1.0 above MSL

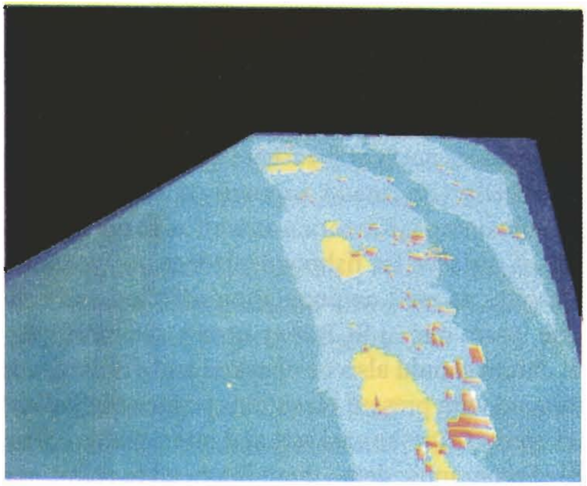

Fig. 9f. Navotas at SLR = 1.25 above MSL

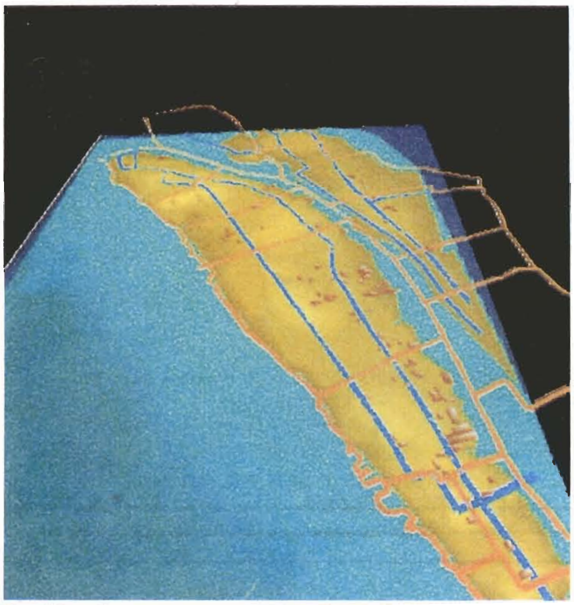

Fig. 10a. 3D view of the Island at 0 m above MSL, shown with administrative boundaries (orange) and major roads (dark blue)

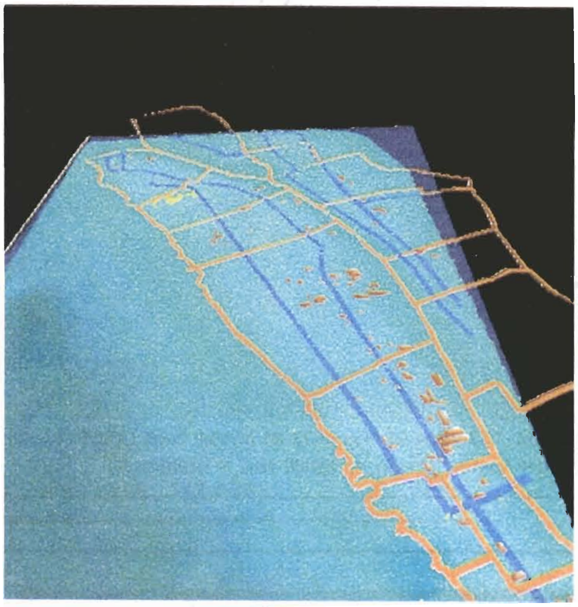

Fig. 10b. 3D view of the Island at SLR = 1.75 above MSL (Note that almost all barangays are submerged in water)

simulation scenarios as well as actual areas affected by flooding. However, most of the roads were submerged during ground observation at high tide (at 1.8 m above MLLW).

Effects of inland flooding due to seasonal and hydrological variations, such as the monsoon, were not considered in the simulation, since quantification of these would need appropriate datasets, and would not consitute long term SLR. Another major area of interest is the possible effects of subsidence on topography.

Fishponds north of the island also were not incorporated in the GIS dataset, primarily due to to difficulties in obtaining information as well as in the interpolation of surfaces for fishponds. Hence, inferred area derivatives as well as population affected and economic losses due to SLR may not be accurate. Vertical datum should also be checked and verified, and compared with present elevations. Since the bulk of work stems from the analysis and interpolation of reliable topographic data, there is a need to refine and improve existing data on the topography of areas in the Philippines. Present data are based mostly on 1:50,000 US Geological Survey (USGS) topographic maps, made via triangulation stations and benchmarks established several decades ago. These maps must be rechecked, and control stations re-observed.

Supplementary topographic data could also be provided by the NASA-JPL Airborne Radar Sensor (AIRSAR), using the Topographic SAR (TOPSAR) Mode. The TOPSAR uses the principle of interferometry to create 3D images of the observed terrain. Interferometry makes use of the difference between Radar signals to derive changes in the observed terrain. This mode of observation enables the acquisition of DEM radar images which could be mapped with at least 1-meter vertical contours. This method of mapping may be utilized to supplement existing topographic maps, obtain elevations, and delineate land-water boundaries. A recent TOPSAR image taken and processed by NASA-JPL verified that the area of Navotas covered by the study is still among the lowest parts of Metro Manila and is still vulnerable to sea-level change *(Personal communication, June 2004)*.

On the overall assessment of the methodology, the technique of integrating 3D modeling with GIS presents an effective way to show spatial information to the users who need to plan and evaluate situations arising from possible sea-level rise. It further provides high resolution spatial data which could be critical in designating valuable resources needed to address the problems posed by flooding and future sea level rise.

ACKNOWLEDGMENTS

- GeoView provided by GeoAnalytika Technical and Engineering Consultants (www.geoanalytika.com).
- Aerial Photography of Navotas (1996) courtesy of NAMRIA.
- Field Observations and Ground Truthing conducted by CEG-CSD Team (Efren Ty, Lysander Gutierrez, Melanie Dychinco and Gerald Galgana), August 2001.

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