I.J.A.B.R, VOL. 4(4) 2014: 416-427 ISSN 2250 – 3579

INTERNATIONAL JOURNAL OF ADVANCED BIOLOGICAL RESEARCH

www.scienceandnature.org

HYDRODYNAMIC MODELING OF LAGOS AND LEKKI LAGOONS

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ABSTRACT
Lagos and Lekki lagoons in Nigeria are water body in the heart of the Lagos metropolis. The two lagoons are interlinked by a waterway. Lagos State is naturally protected by Lekki and Victoria Islands/barrier against wave and tidal action of the Atlantic Ocean. In addition, it is frequently exposed to seasonal rainfall storms that lead to increased water level (retained water depth) of the lagoon due to relatively long residence times and eventually inundation of low-lying and swamp areas. The Nigerian authorities do not permit any breach in the natural barrier to directly release rainfall storm waters into the ocean except the existing Lagos Lagoon outlet. Outfalls are merely permitted around Lagos and Lekki Lagoons. The drainage of rainfall storm water into the lagoons shall result in water volume retention leading to potential increase in water level. The question of how much water level rise due to rainfall storm water discharges requires an answer since there are ongoing and future development around the Lagos and Lekki Lagoons that may be influenced and inundated. As such the knowledge of design water levels around the lagoons is needed for the design of such development. The water level rise due storm water rainfall is considered a dominating component for deriving the design water level of this project. In this regard, this work was carried out to derive the marine design parameters such as design water level. The tool employed for deriving the design parameter is able to model the lagoons with the complex morphological feature. This tool is Delft3D model. In this paper, Delft3D model was utilized to numerically model the lagoons considering tidal driving force, bottom friction, wind stresses as well as mass flux caused by releasing the rainfall storm water. The model was constructed and calibrated. Various scenarios of rainfall storms were simulated and the retained water depth was computed at observation points within the lagoons. The design water level was determined at different places within the lagoons.

KEYWORDS: Lekki and Victoria Islands, Delft3D model, mass flux, tidal action.

INTRODUCTION

Coastal Lagoons are enclosed water basins, with relatively shallow water depths, and situated at the boundary between the land and the ocean. They are usually oriented parallel to the coast and separated from the ocean by a barrier. These lagoons normally have one or a number of streams entering around their perimeter and are connected to the ocean at one or number of inlets. Coastal hydrodynamics of these lagoons are governed by a delicate balance between tidal forces, influxes from the streams, wind stresses, and density induced pressure forces and bottom friction (Imberger and Di Silvio, 1992). Coastal lagoons can be conveniently subdivided into choked, restricted and leaky systems based on the degree of water exchange with the adjacent coastal ocean (Kjerfve, 1986). The choked lagoons are usually found along coasts with high wave energy and significant littoral drift. They are characterized by one or longer and narrow entrance channels, long residence times and dominant wind forcing. Lagos and Lekki lagoons can be categorized as choked lagoons. Lagos lagoon is a water body in the heart of the Lagos metropolis. Lagos lagoon cuts across the southern part of the metropolis, linking the Atlantic Ocean in the south and Lekki lagoon in the east (Fig. 1). Lagos and Lekki Lagoons surface area is about 635 km^2 and 285 km in perimeter. Lagos lagoon is more than 50 km long and 3 to 13 km wide, separated from the Atlantic Ocean by long sand barrier 2 to 5 km wide, which has swampy margins on the lagoon side. The total length of both Lagos and Lekki Lagoons is about 103 km. The lagoons are fairly shallow and are not plied by ocean-going ships, but by smaller and shallow draft barges and boats. The lagoon provides places of abode and recreation, means of livelihood and transport, dumpsite for residential and industrial discharges and a natural shock absorber to balance forces within the natural ecological system. The Lagos Lagoon consists of three main segments; Lagos Harbour, the Metropolitan end and Epe Division segments. Lagos State is naturally protected by Lekki and Victoria Islands/barrier against wave and tidal action of the Atlantic Ocean. In addition, it is frequently exposed to seasonal rainfall storms that lead to increased water level (retained water depth) of the lagoon due to relatively long residence times and eventually inundation of low-lying land areas. The Nigerian authorities do not permit any opening or outlet to release rainfall storms. Alternatively, outfalls are merely permitted around Lagos and Lekki Lagoons. The drainage of rainfall storm water into the lagoons shall result in water volume retention leading to potential increase in water level. The question of how much water level rise due to rainfall storm water discharges requires an answer since there are ongoing and future development around the Lagos and Lekki Lagoons that may be influenced and inundated.

FIGURE 1: Lagos and Lekki Lagoons, Lagos, Nigeria

The tool that could provide a reliable answer, due to the complex morphological feature of the lagoons, is Delft3D model, which is a numerical model developed by Deltares, the Netherlands (see Delft3D-Flow Manual, 2011). In this report, Delft3D model was utilized to numerically model the lagoons considering tidal driving force, bottom friction, wind stresses as well as mass flux caused by releasing the rainfall storm water. The construction of this model was based on collected data that is explained in the following section. This model was employed to determine the increased water level of the lagoons due to releasing the storm waters.

COLLECTED DATA

The construction of hydrodynamic numerical modeling requires data pertaining to water depths (bathymetric survey) of the lagoons and waterways, tidal levels, current, and inflow from the catchment areas distributed around the lagoons. The first step in developing the 2DH hydrodynamic model of the lagoons is to define and collect the basic data required for the model development. These data include the geography and bathymetric data of the lagoons, the basic inflows and outflows from the Lagoons including tide and inflow from streams and the meteorological parameters specially the ones affecting the hydrodynamic analysis.

It is worth mentioning that limited data were available during the development of the model and to note also that measurements for calibration were also very limited. The data that were made available during the model development and calibration include the following:

- The model bathymetry was based on the acquired global bathymetry dataset for the world ocean "GEBCO_08" available at http://www.gebco.net. GEBCO-08 is a global 30 arc-second horizontal resolution (about 900m spacing). Data for the Lagoons were extracted from the global dataset and converted into the appropriate file format for establishing the numerical modeling. The water depths are reduced to lowest astronomical tide while the water depths of the waterways were assumed based on available survey made available from other projects within the lagoons (e.g. Snake Island and Eko Atlantic Island Projects)
- Land boundary was digitized by GIS technique using Google Earth Images.
- Tidal data were obtained from Tide Tables published by Nigerian Navy in 2009, 2010 and 2012 and by UK Hydrographic Office in 2008.
- Current measurements at Snake Island in January 2006.
- Influxes from streams around the lagoons (see Figure 2) were obtained through hydrological analysis for various storm event return periods of 10, 25, 50 and 100 years. The influxes were estimated according to the following assumed scenarios:
  - **Scenario 1:** No reduction to the inflow, rainfall covers the entire catchments areas of 50,000 km^2 in one day storm duration
  - **Scenario 2:** Reduction to the inflow of about 15 to 20% as part of the rainfall water shall be stored within inland ponds, rainfall covers the entire catchments area of 50,000 km^2 in one day storm duration
  - **Scenario 3:** same as scenario 2 but an aerial reduction factor was applied considering that the rainfall partly covers the entire catchment areas in four days storm duration.

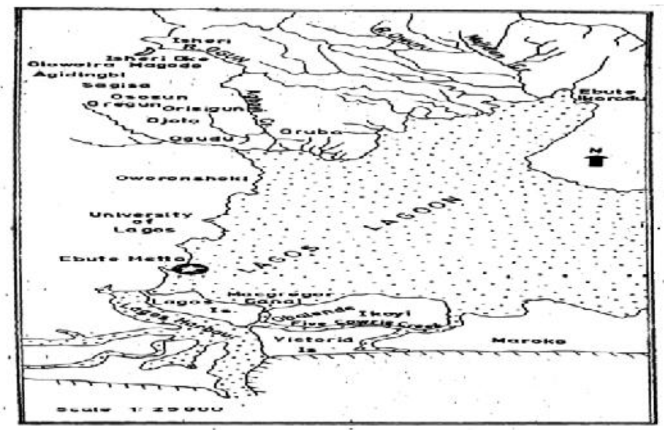

FIGURE 2: Some of streams around Lagos Lagoon (after Lawal-Are and Akinjogunla, 2012)

DEVELOPMENT OF NUMERICAL MODEL

Model Construction

To start with grid generation, a land boundary of the modeled area was obtained. The digitized land boundary of the lagoons as shown in Figure 3 was employed as a base to construct the model curvilinear grid based on UTM Cartesian Coordinate System. The dimensions of the generated grid are 300 x 148 grid cells and the averaged grid size is 35m x 140m at the lagoon's entrance while it is 140 m x 130 m within the lagoons. The grids were made so as to follow the anticipated streamline of the flow field, especially through the waterways. Time step was defined to be 0.50 minutes that provides stable results. Figure 4 shows the generated grid. It is to be mentioned that the Lagos Infrastructure Development (LID project) shown in Figure 4 is one of the developments that needs the determination of the design water level for reclamation and shore protection works. Once the gird was generated, the water depth values reduced to lowest water level, as obtained from GEBCO and available bathymetric surveys within the modeled area, at each grid point were specified. Figure 5 shows the specified water depths used for the hydrodynamic computation. The points, shown on Figure 5, are the observation points where the resulted increased water level is presented in the results section. At this stage, both grid and depth files were created that were used to create the required file for hydrodynamic simulations. The driving force as mentioned above is due to tide action which is specified at the open boundary of the simulated area. The open boundary is that at the entrance of the lagoons.

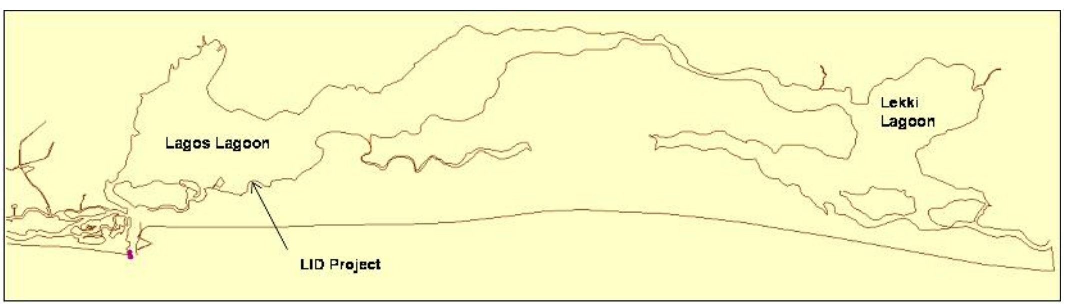

FIGURE 3: Boundary line digitized from Google Earth Image

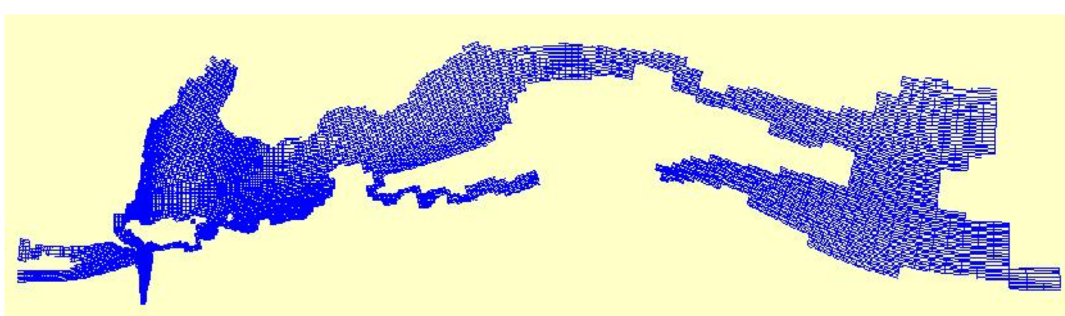

FIGURE 4: Generated gird for Lagos and Lekki Lagoons

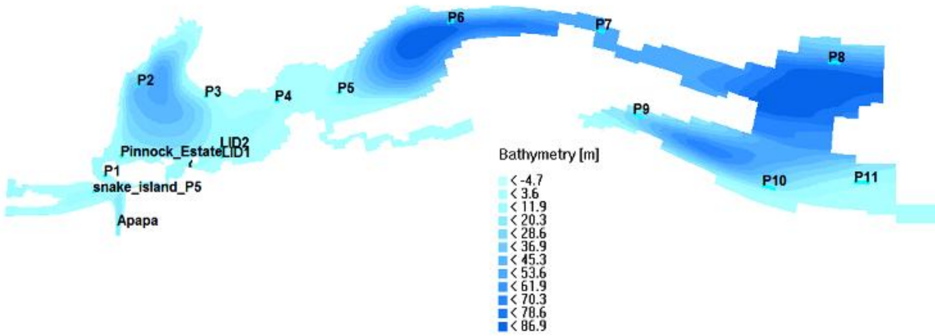

FIGURE 5: water depths of the simulated area. The colored scale represents the water depth values

Boundary Conditions

The nearby city to the open boundary is Apapa at which the tidal constituents, obtained from UK Hydrographic Tide Tables published in 2008, were imposed. The tidal constituents at Apapa are revealed in Table 1.

TABLE 1: Tidal constituents specified at the open boundary of the simulated area

Tidal Constituent	Amplitude (m)	Phase (deg.)
Z_0	0.88	
M_2	0.24	151
S_2	0.07	181
K_1	0.07	31
O_1	0.01	12

As for the extreme water levels, the below is a brief explanation on the available extreme water levels at Lagos Bar and Apapa. It is to be noted that the design level is estimated considering extreme tidal water levels at Lagos Bar since the Mean Sea Level (MSL) at Lagos Bar is the reference datum of the benchmarks employed for the surveys carried out in Nigeria. There are two sources of tide predictions published by Nigerian Navy and UK hydrographic office. According to these publishers, the extreme tidal level data are presented in Tables 2 and 3.

TABLE 2: Extreme Water Levels according to UK Hydrographic Office and Nigerian Navy at Lagos Bar

Extreme Water Levels	UK Hydrographic Office		Nigerian Navy
	Water level (m) relative to LAT	Water Level (m) relative to MLWS	Water Level (m) relative to MLWS
Mean High Water Spring (MHWS)	1.30	1.00	0.945
Mean High Water Neap (MHWN)	1.00	0.70	0.701
Mean Sea Level (MSL)	0.78	0.48	0.457
Mean Low Water Neap (MLWN)	0.50	0.20	0.213
Mean Low Water Spring (MLWS)	0.30	0.00	0.091

TABLE 3: Extreme Water Levels according to UK Hydrographic Office at Apapa:

Extreme Water Levels	UK Hydrographic Office	
	Water level (m) relative to LAT	Water Level (m) relative to MLWS
Mean High Water Spring (MHWS)	1.20	0.90
Mean High Water Neap (MHWN)	1.00	0.80
Mean Sea Level (MSL)	0.88	0.575
Mean Low Water Neap (MLWN)	0.70	0.40
Mean Low Water Spring (MLWS)	0.60	0.20

From the above tables, Tables 2 and 3, Mean Sea Levels at Apapa and Lagos Bar are +0.88m LAT and +0.78m LAT, respectively that are somewhat identical if they are referred to MLWS at Lagos Bar. For design purpose, the water levels obtained at Lagos Bar shall be adopted. Therefore, MHWS, which is approximately +0.50m above MSL at Lagos Bar, was used for deriving the design water level.

Influxes from Streams around the Lagoons

The rating curve, time series, of influxes for the three scenarios stated above at various return periods (10, 25, 50 and 100 years) from twenty catchments around Lagos and Lekki Lagoons was presented as source points in the numerical modeling. The coordinates of the 20 catchments outlets within the modeled area are presented in Table 4.

TABLE 4: Coordinates of the catchments outlets

Catchment Name	Catchment Outlet Location	
	Easting (m)	Northing (m)
Cat 1	635254.10	726846.85
Cat 2	610477.68	727581.31
Cat 3	599977.95	731172.85
Cat 4	585515.01	731907.61
Cat 5	575386.58	729053.63
Cat 6	551339.55	729789.64
Cat 7	544980.70	725103.92
Cat 8	487970.15	719932.14
Cat 9	507496.74	714683.19
Cat 10	511456.61	714961.02
Cat 11	512192.78	717080.70
Cat 12	511549.71	717171.42
Cat 13	487875.83	716250.99
Cat 14	474151.86	713303.84
Cat 15	467518.61	713587.28
Cat 16	634883.68	713664.03
Cat 17	473875.64	713301.46
Cat 18	642997.81	710353.64
Cat 19	643824.19	710723.41
Cat 20	470561.33	713945.79

The influxes for the above mentioned three scenarios at various storm event return periods are estimated based on hydrological analysis.

CALIBRATION OF NUMERICAL MODEL

Current Velocity

In January 2006, current measurements campaign at Snake Island which is located on Badagry Creek was carried out. During this campaign, the current meter was lost and the continuity and retrieval of such measurements was not easily achieved. However, some data were retrieved that were analyzed. The measured current velocity was found to have a maximum current speed of 0.48m/s and directed to east northeast (ebb tide).

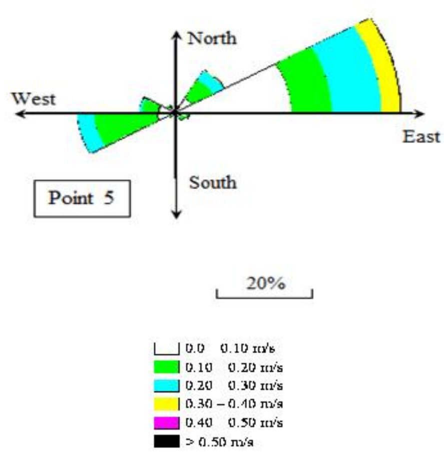

FIGURE 6: Measured Current rose at Snake Island

During flood tide, the measured current speed was found to be 0.25m/s and directed to west southwest. Figure 6 shows the current rose made from the measured current velocity at Snake Island. At the same time of measurements, the current was computed and presented in Figure 7. The maximum computed current speed was found to be 0.43m/s and directed to east northeast during ebb tide. During flood tide, the maximum current speed was found to be 0.36m/s and directed to west southwest. Based on this comparison between the measured and computed current velocities, it can be concluded that the numerical modeling can, to some extent, reproduce and predict reliable current velocity within the modeled area.

Water Level

As for water level, the computed water level was compared to the predicted values at Apapa as presented in Tide Tables published by Nigerian Navy in 2012, as revealed in Figure 8. From Figure 8, the predicted water level by the numerical model satisfactory agrees with the same obtained from Tide Tables published by Nigerian Navy. To assess the time lag between the tidal fluctuation at the entrance of the lagoons and the same at the observation points distributed inside the lagoons, the tidal fluctuation at each point was compared to that at the entrance to obtain the time shift/lag which is illustrated in Table 5. In addition that Table 5 shows the computed tidal range at each observation point.

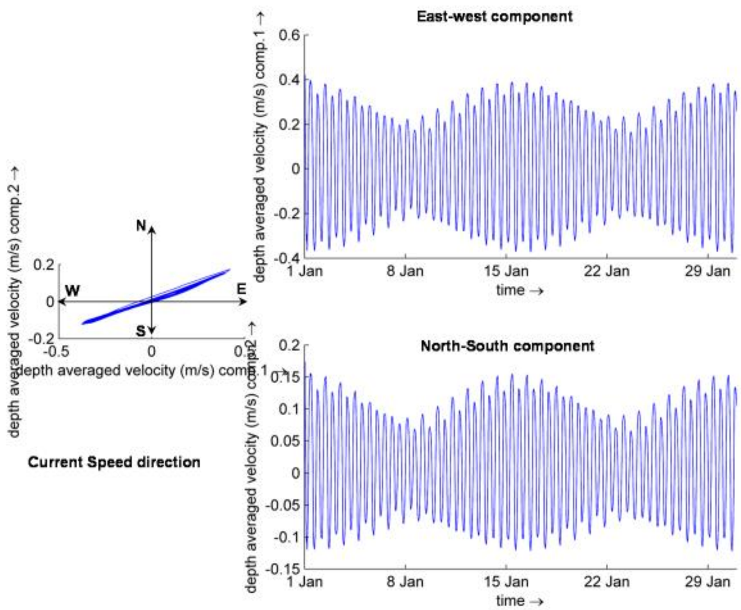

FIGURE 7: Computed current velocity at Snake Island

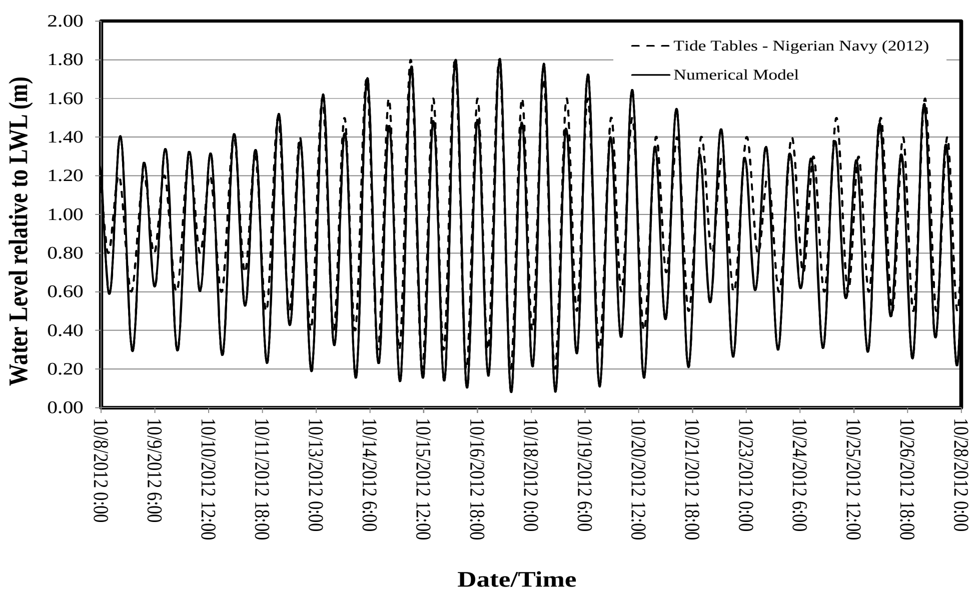

FIGURE 8: Comparison of computed and predicted water levels at Apapa

TABLE 5: Time lag and tidal range at observation points

Point no.	Time lag (min.)	Tidal range (m)
LID	40	0.78
Pinnock	20	0.78
P1	20	1.30
P2	30	0.78
P3	40	0.78
P4	50	0.65
P5	70	0.32
P6	90	0.33
P7	100	0.32
P8	120	0.39
P9	130	0.40
P10	130	0.40
P11	130	0.40

Table 5 reveals that the tidal range, especially at the farthest points, is considerably reduced to relatively half of that at the entrance of the lagoons. In addition that the farthest points have a time lag of about 2 hours and 10 minutes and the resulted tidal range is relatively small. This indicates that the resonance within the lagoon is unlikely. Coastal Engineering Manual (2008), Chapter 7 on Harbor Hydrodynamic provides related explanation that can be used to confirm that resonance is unlikely within the lagoons. According Coastal Engineering Manual, the greatest amplification or resonance, occurs when the natural period (T_n) is identical to the cyclic excitation (tide) period (T). No or limited amplification exists when (T_n/T) is smaller or larger than 1. The natural period of the closed basin is estimated as:

$$T_n = \frac{2\, l_B}{\sqrt{gd}}$$

Where (l_B) is the length of the basin, (g) is the acceleration of gravity and (d) is the average water depth. The length of the lagoons is about 103 km and the average water depth is about 19.5m. Substituting in the above equation, the natural period of the lagoons is equal to 4.14 hr. The semidiurnal tide period is 12 hr and 25 min (12.41 hr). Accordingly, the ratio of (T_n/T) is about 0.33 so that the amplification or resonance is unlikely to occur.

NUMERICAL MODEL SIMULATIONS

After checking the reliability and validity of numerical model results acquainted through the model calibration performed and presented above, 17 simulation runs were conducted to predict the lagoon water level rise due to influxes of streams found around the perimeter of the lagoons and along the Badagry Creek leading to the lagoons. These simulations were summarized in the below table (Table 6). The rainfall storm event was assumed to commence on October 19, 2012 and end by the beginning of November 2012. As such the simulation time was set to be 1.5 months that commences on the first of October 2012 and end by the mid of November 2012.

TABLE 6: Description of model simulations

Simulation no	Description
1	Scenario 1 without tide action and storm event with 100 year return period for Scenario 1
2	Scenario 1 with tide action and storm event with 10 year return period
3	Scenario 1 with tide action and storm event with 25 year return period
4	Scenario 1 with tide action and storm event with 50 year return period
5	Scenario 1 with tide action and storm event with 100 year return period
6	Scenario 2 with tide action and storm event with 10 year return period
7	Scenario 2 with tide action and storm event with 25 year return period
8	Scenario 2 with tide action and storm event with 50 year return period
9	Scenario 2 with tide action and storm event with 100 year return period
10	Scenario 3 with tide action and storm event with 10 year return period
11	Scenario 3 with tide action and storm event with 25 year return period
12	Scenario 3 with tide action and storm event with 50 year return period
13	Scenario 3 with tide action and storm event with 100 year return period
14	Scenario 3 with tide and wind actions and storm event with 10 year return period
15	Scenario 3 with tide and wind actions and storm event with 25 year return period
16	Scenario 3 with tide and wind actions and storm event with 50 year return period
17	Scenario 3 with tide and wind actions and storm event with 100 year return period

The computed water levels were observed at 13 observation points distributed inside the lagoons. The location of these points can be found on Figure 5 and their coordinates are revealed in Table 7. It is to be noted that point "LID" is the point located off the Lagos Infrastructure Development (LID) Project. Point no. "Pinnock" is located off Pinnock Estate which is located close to LID project. Simulation no. 1 was made to examine the behavior of releasing the storm water discharges and to compute the induced retained water depth without tidal action. The last four simulations from 14 to 17 were conducted to examine the action of wind that is blown from the predominant direction of southwest with an assumed extreme value of 15 m/s.

TABLE 7: Coordinates of Observation points

Point no.	Easting (m)	Northing (m)
LID	556617.81	715658.25
Pinnock	544555.63	715759.13
P1	542544.75	713364.63
P2	546576.94	723786.63
P3	554686.19	722505.19
P4	563139.63	722065.31
P5	570630.50	723052.81
P6	583958.50	731091.88
P7	601834.94	730087.00
P8	629760.25	726490.56
P9	606330.50	720302.56
P10	622091.38	712157.69
P11	633303.81	712633.69

Influence of Tide Action

The influence of tide action on releasing the storm water discharge and the induced retained water depth was examined. Table 8 shows the maximum retained water depth (lagoon water level rise) at the observation points in case of releasing storm water discharges with 100 year return period without tide action (simulation no. 1) and with tide action (simulation no. 5). The presented values of water level rise were approximated to the nearest 5 centimeters.

TABLE 8: Maximum sea level rise due to storm water discharge without tide action (simulation no. 1) and with tide action (simulation no. 5)

Point no.	Simulation no. 1	Simulation no. 5
LID	2.40	2.30
Pinnock	2.40	2.25
P1	1.55	1.50
P2	2.40	2.30
P3	2.40	2.30
P4	2.40	2.30
P5	2.50	2.20
P6	2.50	2.20
P7	2.50	2.20
P8	2.50	2.25
P9	2.50	2.25
P10	2.50	2.25
P11	2.50	2.25

The above comparison indicates that the tide action accelerates emptying the lagoons so as the retained water depth is smaller in the case of considering tide action than the case without tide. Consequently, the tide action should be accounted for in similar simulation cases since it is the realistic phenomenon.

Influence of Wind Action Wind action was applied for scenario 3 with various storm event return periods. The computed maximum water level rise at the observation points was compared for the two cases with and without wind action as shown in Table 9. The maximum water level rise for the two cases has occurred at different phases so that the residual water level rise due to wind only should not be estimated by subtracting these values. The temporal variation of water level rise for the cases without and with wind action and the resulted residual water level rise due to wind only at the observation point (P11) is presented in Figure 9 for simulation no.17.

TABLE 9: Maximum sea level rise due to storm water discharge without wind action (simulation nos. 10, 11, 12 and 13) and with wind action (simulation no. 14, 15, 16 and 17)

Point no.	Without wind action – Simulation no.				With wind action Simulation no.			
	10	11	12	13	14	15	16	17
LID	0.75	1.05	1.30	1.60	0.80	1.10	1.35	1.60
Pinnock	0.75	1.00	1.30	1.50	0.80	1.10	1.30	1.60
P1	0.50	0.70	0.80	1.00	0.50	0.70	0.85	1.00
P2	0.75	1.05	1.30	1.60	0.80	1.10	1.35	1.60
P3	0.75	1.05	1.30	1.60	0.80	1.10	1.35	1.60
P4	0.75	1.05	1.30	1.60	0.90	1.20	1.40	1.70
P5	0.75	1.05	1.30	1.50	0.90	1.20	1.45	1.70
P6	0.80	1.05	1.30	1.50	0.95	1.25	1.50	1.70
P7	0.80	1.05	1.30	1.50	1.00	1.25	1.50	1.70
P8	0.80	1.05	1.30	1.60	1.00	1.30	1.50	1.70
P9	0.80	1.05	1.30	1.60	1.00	1.25	1.50	1.70
P10	0.80	1.05	1.30	1.60	1.00	1.25	1.50	1.70
P11	0.80	1.05	1.30	1.60	1.00	1.30	1.50	1.75

It should be once again noted that the residual water level rise presented in Figure 9 was derived according to the action of an assumed wind speed of 15 m/s exerted from the prevailing southwest direction. The spatial distribution of water level rise due to wind only is presented in Figure 10. Figure 9 and 10 show that the residual water level rise due to wind only increases at Lekki lagoon in comparison to the same at Lagos Lagoon. The reason is that the fetch in the SW direction of wind is quite longer for the Lekki Lagoon. The maximum residual water level rise due to wind (wind setup) is found to be 0.25m. The storm surge is the increased water level due to wind and atmospheric pressure.For design purposes when deriving the design water level, the sea level rise due to storm surge by meteorological effects (wind and atmospheric pressure) shall be accounted for.

Simulations Results

As indicated above, the key component for deriving the design water levels for the projects located within Lagos and Lekki Lagoons is the water level rise due to rainfall storm water discharges. Table 10 provides the maximum observed sea level rise at the observations points for all simulation runs. To derive the design water level at LID project, the water level rise due to rainfall at point "LID" is considered and added to the Mean High Water Spring, storm surge due to wind and atmospheric pressure and sea level rise due to global warming considering the project lifetime of 50 years.

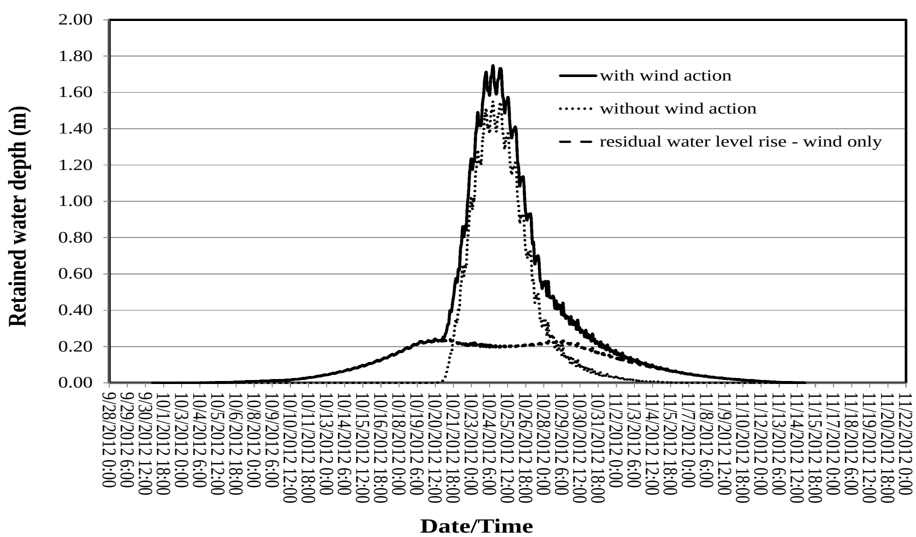

FIGURE 9: Water level rise for scenario 3 for storm event 100 year return period with wind (simulation no. 17) and without wind (simulation no. 13) and the residual water level rise due to wind only at observation point P11

TABLE 10: Maximum sea level rise at observation points for all simulation runs

Point no.	Simulation no																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
LID	2.40	1.20	1.60	2.00	2.30	0.90	1.25	1.50	1.90	0.80	1.10	1.35	1.60	0.80	1.10	1.35	1.60
Pinnock	2.40	1.20	1.60	2.00	2.25	0.90	1.20	1.50	1.85	0.75	1.00	1.30	1.50	0.80	1.10	1.30	1.60
P1	1.55	0.80	1.05	1.35	1.50	0.60	0.80	1.00	1.20	0.50	0.70	0.80	1.00	0.50	0.70	0.85	1.00
P2	2.40	1.20	1.60	2.00	2.30	0.90	1.25	1.50	1.90	0.75	1.05	1.30	1.60	0.80	1.10	1.35	1.60
P3	2.40	1.20	1.60	2.00	2.30	0.90	1.25	1.50	1.90	0.75	1.05	1.30	1.60	0.80	1.10	1.35	1.60
P4	2.40	1.20	1.60	2.00	2.30	0.90	1.25	1.50	1.90	0.75	1.05	1.30	1.60	0.90	1.20	1.40	1.70
P5	2.50	1.20	1.60	2.10	2.20	0.90	1.20	1.50	1.80	0.75	1.05	1.30	1.50	0.90	1.20	1.45	1.70
P6	2.50	1.20	1.60	2.10	2.20	0.90	1.20	1.50	1.80	0.80	1.05	1.30	1.50	0.95	1.25	1.50	1.70
P7	2.50	1.20	1.60	2.10	2.20	0.90	1.20	1.50	1.80	0.80	1.05	1.30	1.50	1.00	1.25	1.50	1.70
P8	2.50	1.20	1.60	2.10	2.25	0.90	1.20	1.50	1.80	0.80	1.05	1.30	1.60	1.00	1.30	1.50	1.70
P9	2.50	1.20	1.60	2.10	2.25	0.90	1.20	1.50	1.80	0.80	1.05	1.30	1.60	1.00	1.25	1.50	1.70
P10	2.50	1.20	1.60	2.10	2.25	0.90	1.20	1.50	1.80	0.80	1.05	1.30	1.60	1.00	1.25	1.50	1.70
P11	2.50	1.20	1.60	2.10	2.25	0.90	1.20	1.50	1.80	0.80	1.05	1.30	1.60	1.00	1.30	1.50	1.75

Discussion was made on the scenario that should be adopted for deriving the design water level. According to the study of the available satellite images for the cloud coverage and typical storm durations, it was decided to adopt the third scenario which applies aerial reduction factor and 15 to 20 % reduction as part of the rainfall amount is stored with the inland ponds while the storm duration is four days. Based on the above, Table 11 reveals the water level rise due to rainfall at LID project with different return periods of 10, 25, 50 and 100 years.

The other components of the design water level to be considered are as follows:

- Mean High Water Spring (MHWS) = +0.50m MSL
- Storm Surge due to Meteorological Effects = 0.50 m (considering 0.25m due to atmospheric pressure)
- Sea Level Rise due to global warming = 0.30m (According to IPCC, 2007 considering a lifetime of 50 years)

Accordingly, and adding up the components presented above, the design water level would be as shown in Table 12.

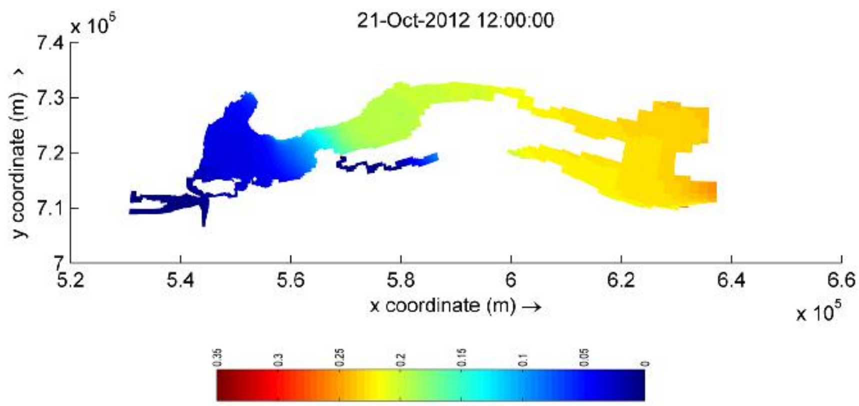

FIGURE 10: Spatial distribution of residual water level rise due to wind only – derived values from water level rises resulted from simulation no. 13 and 17. The colored bar represents the values of the residual water level rise.

TABLE 11: Maximum sea level rise at LID Project after applying 10% due to uncertainty of estimating the rainfall storm water into the lagoon.

Return Period (year)	Water Level Rise due to Rainfall (m)
10	0.80
25	1.10
50	1.35
100	1.60

TABLE 12: Design water level at LID Project for 10, 25, 50 and 100 years return period of rainfall storm events

Return Period (year)	Design Water Level (m) above MSL
10	+2.10
25	+2.40
50	+2.65
100	+2.90

CONCLUSIONS

Delft3D numerical model was employed to provide an answer to the anticipated value of water level rise (retained water depth) within Lagos and Lekki Lagoons due to influxes from streams entering around the perimeter of the lagoons. The hydrodynamics of the lagoons are mainly governed by a delicate balance between tidal forces, influxes from the streams, wind stresses and bottom friction. Delft3D model can model such case with these hydrodynamic interactions. The model was well calibrated using available current measurements carried out at one of the project site within Badagry Creek in addition to the tidal prediction made available and published by Nigerian Navy in 2012. The model results (water level rise due to rainfall) were found to be significantly affected by the tidal action. Comparison was made between simulations with and without tidal action and it is inferred that the tidal action accelerate emptying the rainfall storm water since the computed water level rise with tidal action was found to be less than the same while ignoring the tidal action. Simulation runs were performed to address the effect of wind. Wind action induces setup that is superimposed to the water level rise due to rainfall. The wind setup is found to be large at Lekki lagoons due to the long fetch at the same direction of the applied prevailing SW wind.

The design water level was estimated and presented in Table 12 at LID project which is located at 18 km east of Lagos downtown. It is to be noted that the numerical model results do not cater for the future development (land reclamation) within the lagoons since such development may increase the resulted water level rise due to rainfall. The future development shall reduce the storage volume of the lagoons. As such it is highly recommended to carry out numerical simulations to check the resulted value and to cater for the future development (land reclamation) within the lagoons.

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