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DETERMINATION OF HIGHEST SEA WATER LEVEL AT DRAINAGE CHANNEL OUTLET OF THIRD RING ROAD IN TRIPOLI, LIBYA

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إيجاد أعلى مستوى لمياه البحر عند مخرج قناة تصريف مياه الأمطار للطريق الدائري الثالث بمدينة طرابلس، ليبيا

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الملخص

يعتبر الطريق الدائري الثالث أحد المشاريع الإستراتيجية التي بدأ جهاز تنفيذ مشروعات الإسكان والمرافق في استكمالها في نهاية 2023 لغرض تقليل الازدحام المروري داخل مدينة طرابلس بليبيا وربط مناطق جنوب طرابلس بوسط المدينة. تم تصميم الطريق بحيث تبدأ تقريبا من بداية الطريق الدائري الثاني وتنتهي بالقرب من الساحل بالتقاطع مع الطريق الساحلي. من أجل تصريف مياه الأمطار التي تتجمع على سطح الطريق، تم تصميم قناة خرسانية صندوقية على طول مسار الطريق لنقل وتصريف مياه الأمطار المتجمعة عبر مخرج مفتوح على البحر. وحيث أن مستوى سطح البحر يتذبذب إلى أعلى وإلى أسفل إما بشكل يومي نتيجة تأثير ظاهرة المد والجزر أو بشكل متكرر نتيجة تأثير الأمواج والعواصف أو يزيد سنويا بشكل تدريجي تحت تأثير ظاهرة التغير المناخي، فإن هذا يستوجب أن يكون قاع قناة التصريف أعلى من أقصى منسوب يمكن لسطح البحر أن يبلغه وذلك لتقادي حالة الغمر لمخرج القناة. في هذه الدراسة، تم إيجاد أقصى مستوى لسطح البحر تحت تأثير الظواهر المذكورة سالفا خلال فترة رجوع بلغت 50 سنة. تم استخدام نموذج عددي لانتقال الأمواج لإيجاد الارتفاع الناتج من تأثير الأمواج في المنطقة المحيطة بموقع المخرج. كما تم استخدام طريقة تحليلية مبسطة لإيجاد الارتفاع أثناء العواصف نتيجة الانخفاض في قيمة الضغط الجوي وإجهاد الرياح القصي على سطح البحر. بالنسبة لمتوسط أقصى ارتفاع للمد الفلكي فقد تم الحصول عليه من جداول المد البحرية، بينما تم الحصول على قيمة الارتفاع الناتج من التغير المناخي من دراسة حديثة أجريت لحوض البحر الأبيض المتوسط. النتائج بينت أنه من غير المتوقع أن يتعرض مخرج القناة لحالة الغمر.

الكلمات المفتاحية: ارتفاع مستوى مياه البحر، المد الفلكي، المد العاصفي، التغير المناخي.

ABSTRACT

The Third Ring Road (TRR) is one of the strategic projects that the Housing and Infrastructure Board (HIB) started its completion works at the end of 2023 for the purpose of reducing traffic congestion inside the city of Tripoli and to connect the southern regions

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of Tripoli to the center of the city. The road is designed to start from nearly the beginning of the existing second ring road and to end near the coast at an intersection with the coastal road. To drain the storm water collected from the road surface, a concrete box channel was designed along the whole of the road to convey and drain the collected water into the sea through an open outlet. Since the sea water level is fluctuating up and down on a daily basis due to astronomical tide or frequently due to wave and storm effects or gradually rising on an annual basis due to climate change effect, the invert level of the outlet should be higher than the highest level that the sea surface could reach to avoid the condition of outlet submergence. In this study, the highest sea water level has been determined under the aforementioned effects within a return period of 50 years. A numerical wave propagation model was used to determine the rise due to wave setup in the vicinity of the outlet location. A simplified analytical method was used to determine the rise during storms due to low atmospheric pressure and wind shearing stress on the sea water surface. The average of highest astronomical tide was obtained from Admiralty Tide Tables, while the rise due to climate change was obtained from a recent study on the Mediterranean basin. The results showed that the outlet is not expected to encounter a submergence condition.

KEYWORDS: Sea water level rise, astronomical tide, storm surge, climate change.

INTRODUCTION

The Third Ring Road (TRR) is one of the strategic projects that the Housing and Infrastructure Board (HIB) started its completion works at the end of 2023 for the purpose of reducing traffic congestion inside the city of Tripoli in Libya and to connect the southern regions of Tripoli to the center of the city. The road starts from the roundabout of Ghot Ashal in the West of the city and extends to the east direction in a roughly parallel path to the Second Ring Road (SRR) and South of it until the region of Saba (Figure 1). Then, it goes to the North to intersect with SRR and ends at the First Ring Road (FRR) known as coastal road at a total length of 23.8 km.

Figure 1: Ariel view of TRR path [1].

The TRR is a two-way highway composed of three lanes and emergency lane in each direction. The TRR contains 14 intersections and 14 pedestrian bridges. For the purpose of draining storm water flowing over the road surface, a closed concrete box channel was designed with a width of 3 m and height of 2 m along the whole path of the road to drain the collected water in the sea through an outlet located at the shore. A number of outlet locations has been suggested as shown in Figure (2). The channel was designed as a gravity flow system with an invert level of the outlet at +2.15 m above mean sea level (MSL).

Since the sea water level is fluctuating up and down on a daily basis due to astronomical tide or frequently due to wave and storm effects or gradually rising on an annual basis due to climate change effect, the invert level of the outlet should be higher than the highest sea water level to avoid the condition of outlet submergence. The condition of outlet submergence affects the channel flow capacity in that it reduces the flow velocity due to the effect of backwater.

This study aims to determine the highest potential sea water level to ensure the non-occurrence of submergence condition to the outlet, which leads to reducing the drainage capacity of the channel and the possibility of impounding water at the surface of the road.

Figure 2: Suggested locations of drainage channel outlet.

STUDY APPROACH

Study works in coastal regions are characterized with the effect of several climatic, natural and physical phenomena and factors such as astronomical attractions, winds, atmospheric pressure, sea waves, natural composition of sea bed and water depths in addition to climate change. These factors have a direct effect on the variation of sea water level such that the range of variation reaches several meters depending on the geographic

location on the earth and the extent of astronomical attraction effect, marine storms and climate change.

Since the effect of wave setup largely depends on the characteristics of nearshore waves that largely depend on water depths, it is locally important to study the variation of sea water level under the effect of the aforementioned phenomena such as tidal cycles, storm surges, atmospheric pressure, and wave setup in addition to climate change. Accordingly, the determination of highest sea water level requires collecting data on tidal cycles, climate change, atmospheric pressure, water depths, winds, and waves. In addition, the processes of generation, motion and propagation of sea waves are so complex that the mathematical formulation describing these processes is solved using numerical methods. This means that the analysis of sea waves requires implementation of complicated numerical simulation models to achieve accurate results.

The model of simulating waves nearshore known as SWAN [2] was used to simulate the propagation of waves from the offshore region to the locations of the outlet at the nearshore region. The implementation of wave simulation requires collecting and analyzing offshore and nearshore bathymetric data, average astronomical tide, prevailing wind and wave data. The offshore bathymetric data was collected from global sources, while nearshore bathymetric was obtained from Ministry of Marine Wealth in Libya. The astronomical tide data will be collected from global observation resources. A simplified analytical method was used to determine the rise in water level due to storm surges.

BATHYMETRIC DATA

The bathymetric data were collected from two main sources: 1) international survey sources; 2) local survey sources. With regard to international sources, the General Bathymetric Chart of the Oceans [3] known as GEBCO provides free of charge bathymetric maps with a spatial resolution of 450 m along the Libyan coast. In addition, the European Marine and Observation Data Network (EMODnet) provides more precise bathymetric data with a spatial resolution up to 112 m along the Libyan coast. The main source of these data are from hydrographic surveys accomplished with Light Detection and Ranging (LiDAR) technology or Multi-Beam Echo-Sounder (MBES) technology. Both survey processes undergo quality assurance (QA) and quality control (QC) procedures to ensure the accuracy of data before being released to public. The bathymetric data map was prepared according to the data obtained from EMODnet database with a spatial resolution of 112 m covering the whole region (Figure 3).

In relation to local sources, it was relied on previous studies conducted near the area under study that were provided by the Libyan Ministry of Marine Wealth represented in two principal studies. The first one is wave and navigational study for layout improvement of Tajura fishing harbour conducted by SOGREAH CONSULTANTS in 2005 [4]. The second study is the hydrographic survey of the region around Tripoli Fishing Port in Tajura conducted by AKTI ENGINEERING in 2009 [5]. The international and local bathymetric data were merged together to obtain more accurate results along the nearshore area where the boundaries of survey area extended 45 km in the East-west direction and 45 km in the North direction up to a depth of 200 m (Figure 3).

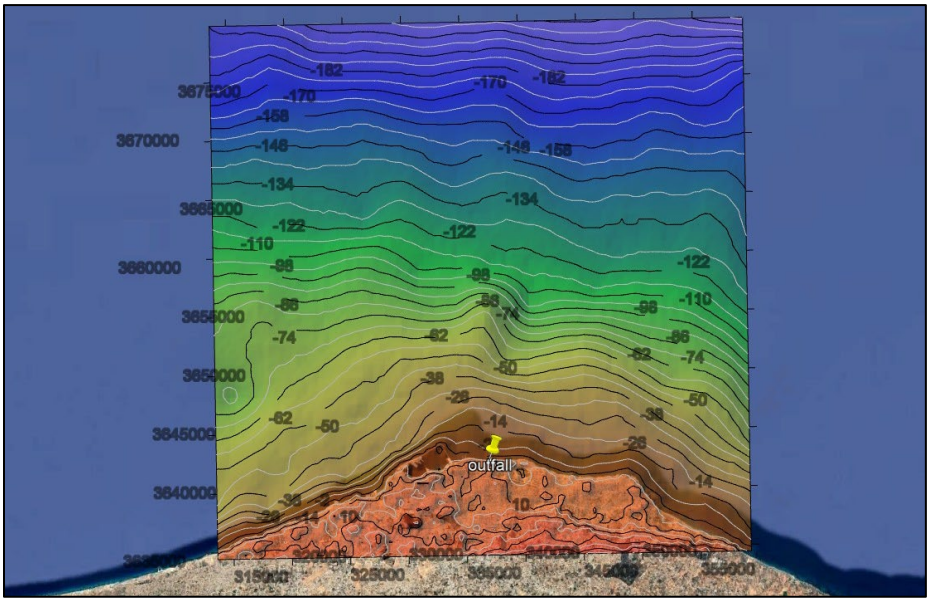

Figure 3: Bathymetric data and boundaries of the study area.

WIND DATA

The wind data were provided by Libyan National Meteorological Centre (LNMC) and obtained from the technical study conducted by TRITON CONSULTING ENGINEERS in 2011 [6] as part of the design study of Tripoli fishing port located in Tajura as shown in Figure (4). These data show that the prevailing wind direction is North-West where the wind speed exceeds 13.9 m/s. The data are consistent with the results of wave and navigational study for layout improvement of Tajura fishing port carried out by SOGREAH CONSULTANTS in 2005 [4] and also the redesign study of Tripoli western breakwater conducted by De Weger in 1998 [7]. According to the evaluation study of Tripoli western breakwater design conducted by De Weger in 1998 [7], the maximum wind speed for the extreme storm recorded in NW direction was 30 m/s. As such, the maximum wind speed of 30 m/s was used in this study.

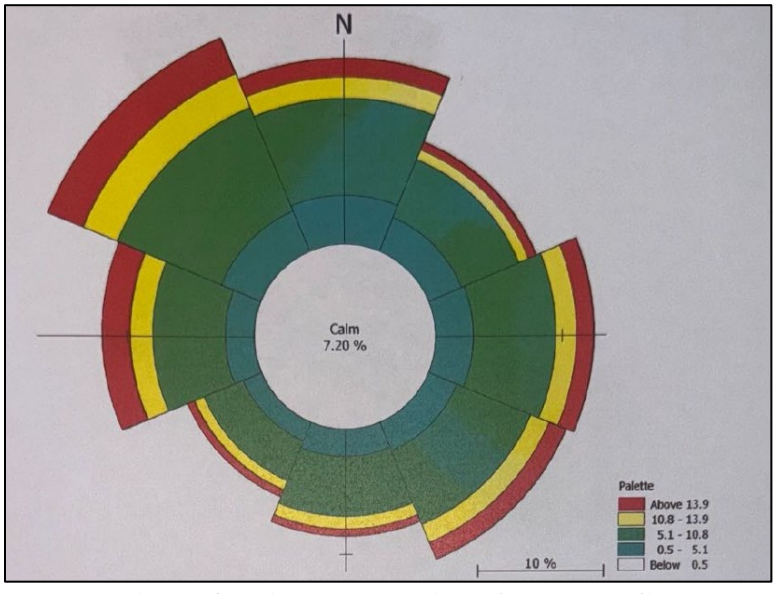

Figure 4: Wind rose obtained from LNMC.

WAVE DATA

According to the data obtained from previous studies conducted near the area under study that are represented three studies. First, the technical study for evaluation of Tripoli western breakwater redesign carried out by De Weger in 1998 [7]. Second, the technical study for layout improvement of Tajura fishing port in Hamedya region conducted by SOGREAH CONSULTANTS in 2005 [4]. Lastly, the technical study for design of Tripoli fishing port located in Tajura and conducted by TRITON CONSULTING ENGINEERS in 2011 [6]. All these studies show an agreement on that the prevailing wave direction is North-West and according to the analysis of wave data, the design wave height for a return period of 50 years is 9.4 m and the wave period is 14.5 sec.

TIDE DATA

In Libya, there are no local observation points for recoding variation of sea water level under the effect of astronomical tide. As such, it was relied on reliable international sources in this context of which the most important is the United Kingdom Hydrographic Office [8], which has a database covering 500 main ports and 5700 secondary ports around the world (Figure 5). The office publishes Admiralty Tide Tables in a yearly basis in eight volumes and each volume covers a specified region. Libya is covered in volume 8 that includes Tripoli commercial port, which is the nearest point to the location of study area. According to these tables, the average high water level (MHWL) is at 50 cm above MSL.

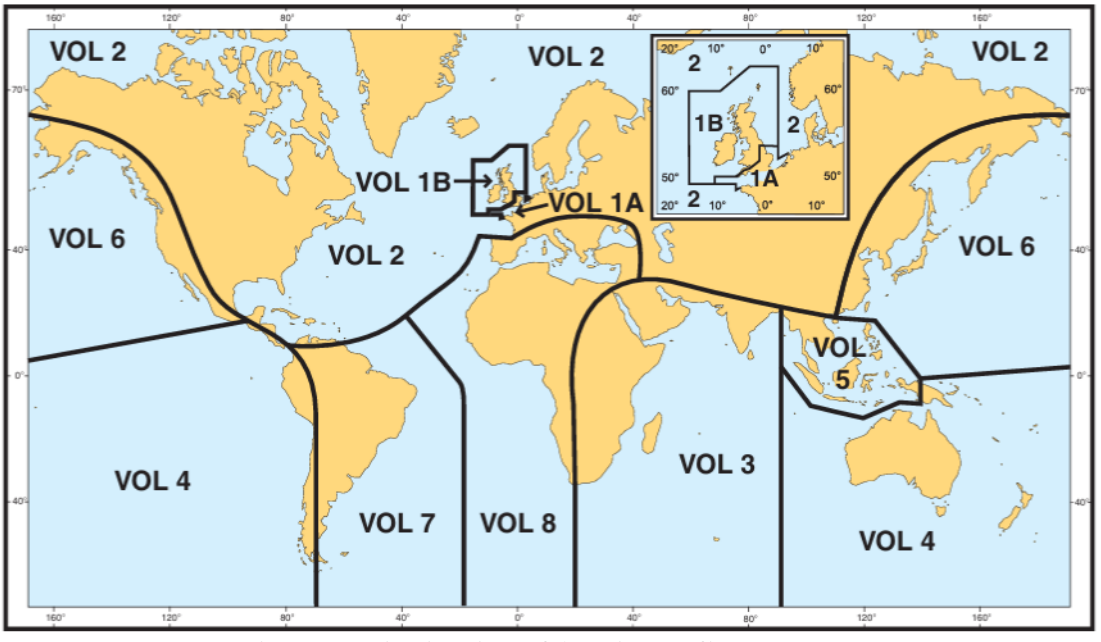

Figure 5: Distribution of Admiralty Chart Tables.

STORM SURGE EFFECT

The occurrence of marine storms in the deep sea is accompanied with low atmospheric pressures and strong winds. The low atmospheric pressure has the effect of raising the sea water level due to the surface expansion in addition to raising the water

level as a result of pushing the surface by the strong wind to the shore region to form the phenomenon of storm surge.

To determine the value of sea level expansion due to lowering of atmospheric pressure to (P_a) under the normal pressure taken at 1013 mbar, the following equation is used:

$$\text{Low Pressure effect} = 0.01(1013 - \mathrm{P_a}) \quad (1)$$

Considering the design wind speed at 30 m/s will result in lowering atmospheric pressure to a value of 983 mbar, the corresponding rise in sea water level will be 30 cm.

To determine the rise in sea water level due to pushing the water surface by the wind towards the shore and according to a simplified analytical method [9], the following equation is used:

$$\text{Wind Stress Effect} \approx \mathrm{d}\left[\sqrt{\frac{0.000006W^2X}{\mathrm{gd}^2} + 1} - 1\right] \quad (2)$$

For an average water depth ($d = 25\ m$) at the coastal region, wind speed ($W = 30\ m/s$), and the fetch distance ($X = 45\ km$), acceleration due to gravity g of 9.81 m^2/s, the corresponding rise in sea water level is 50 cm.

CLIMATE CHANGE EFFECT

According to a recent climatic study related to the evaluation of sea water level rise along the Libyan coast due to the effect of climate change jointly conducted by international organizations, namely World Bank (WB), United Nations Development Program (UNDP), and European Union (EU), as part of the study report of Rapid Damage and Needs Assessment (RDNA) published in 2023, the rise in sea water level is expected to be at a rate of 6.8 mm/year. This rate is based on satellite altimetry measurements observed from 1993 to the present provided by the altimetry dataset of "Archiving, Validation and Interpretation of Satellite Oceanographic data" known as AVISO [10] (Figure 6).

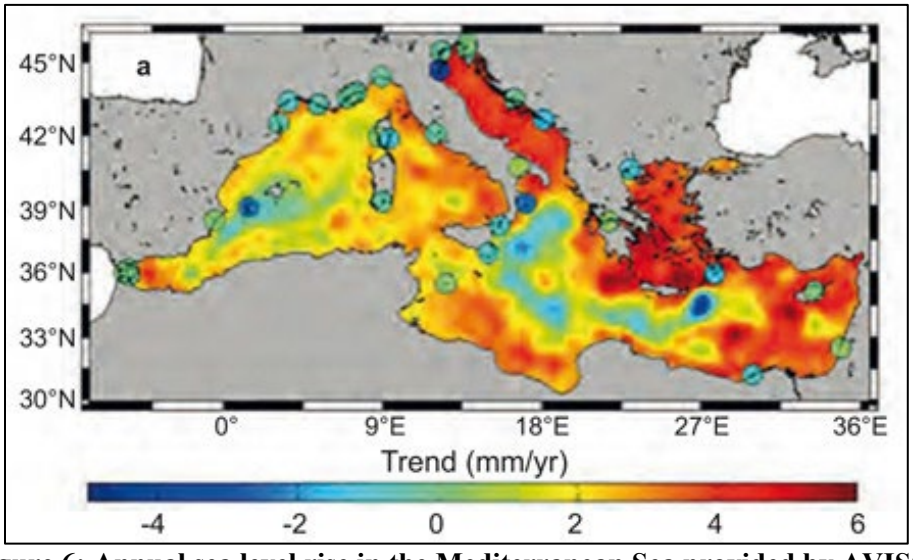

Figure 6: Annual sea level rise in the Mediterranean Sea provided by AVISO.

WAVE PROPAGATION MODELLING

The numerical modelling of wave propagation starting from the place of generation due to the exposure of sea surface to wind effect in the offshore regions in deep water to the coastal or nearshore region is the main factor in designing coastal marine structures. Through wave modelling, final wave characteristics can be determined as a result of physical processes effect a wave undergoes in combination with the effect of shallow water, topographic shape and natural composition of the seabed.

Due to the complexity of physical processes of wave motion and seabed characteristics that essentially requires borrowing precise and accurate methods capable of simulating the real sea state, the methods of numerical modelling are used in wave analysis because of being characterised with high accuracy in handling and dealing with complex mathematical formulations that describes the motion of waves.

The model of Simulating Waves Nearshore (SWAN), which is a third generation and state-of-the-art model, is the most common model used worldwide for the analysis of wave propagation in the design of coastal marine structures. In this study, the model of SWAN was applied using the most recent version to obtain best and most accurate results of wave characteristics in the area under study.

SWAN MODEL

SWAN is one of third generation wave simulation models initially developed in the Netherland by TU Delft University and with support from United States Office of Naval Research in 1999. Since then, the model has been continually updated by TU Delft University and Dutch Ministry of Transportation and Water Management in accordance with scientific development in the field of wave simulation and propagation. The model of SWAN is specifically designed to simulate wave propagation from the deep sea to the nearshore zones and unlike other models such as WAM and WAVEWATCH III that specialized in simulating waves in the offshore zones.

SWAN is characterized with high accuracy in addition to being available for free. This is why SWAN widely spread in several countries and being relied on in the field of wave climate forecast in addition to being used in the design works of coastal structures particularly all types of ports.

SWAN does not require graphical interface and is executed using a programmed commands saved in a core command file. The command file is linked to a set of data files like bathymetric and wind data, which are called during the execution of the model. The model is operated on MS-DOS platform and, when completed, the output results are stored in the form of tabulated data that helps in archiving and saving the data. For further presentation of model results in the form of figures, the use of processing tools are required.

APPLICATION OF SWAN TO THE STUDIED AREA

The model of SWAN was set up to the area of study to simulate the propagation of waves generated at the offshore boundary until they reach the shore. Several considerations were taken into account to achieve the best and most accurate results by the model:

- First, extending the boundaries of the computational grid to avoid transferring the boundary errors to the area of study such that the boundary is away from the area

of study by a distance of 22 km in the east direction, 23 km in the west direction, and 37 km in the north direction, which are more than enough for this purpose.

- Second, applying highest possible level of spatial resolution at a value of 90 m, which is close to the highest recommended value (50-1000) m.
- Third, incorporation of different physical processes that waves undergo when transferring from deep water to shallow water such as white capping, wave-wave interaction, wave breaking, bottom friction, wave refraction, wave shoaling.
- Fourth, using most recent wave spectrum for representing waves known as JONSWAP spectrum for simulating wave generation and propagation.
- Lastly, incorporation of the effect of astronomical tide, storm surge, climate change on raising sea water level to determine highest value of wave setup on the coastal region.

The simulation was conducted using the most extreme marine storms with a return period of 50 years coming from the prevailing direction, which is NW direction, with a design wave height of 9.4 m and wave period of 14.5 sec. Application of operational conditions that correspond to wave incidents of 4.4 m in height and 11 sec in period with a return period of 5 years were also applied. In addition, the other wave directions, which are N and NE, were applied to validate the prevailing wave direction.

MODEL RESULTS

Table (1) below shows a screen shot of the output file of model results at the suggested outlet locations set in the model. The results in the table include horizontal coordinates (Xp) in meters, vertical coordinates (Yp) in meters, sea bottom level in meters, water depth in meters including the effect of astronomical tide, storm surge, wave setup, and climate change, wave setup in meters, and significant wave height (Hsig) in meters.

Evidently, the results show that, on average, the wave setup affecting the region is approximately 40 cm. Accordingly, the total rise including astronomical tide, storm surge, wave setup, and climate change is 2.04 m. It is worth emphasizing that this condition rarely occurs with an average probability of occurrence of once every 50 years.

To determine more frequent storm incidents, the operational conditions were applied that showed an average value of wave setup at 23 cm as shown in the Table (2). Accordingly, the total rise including astronomical tide, storm surge, wave setup, and climate change is 0.964 m. This rise is expected to occur once every 5 years.

Table 1: Wave setup and height results for the extreme condition.

Run:001 Table:A1 SWAN version:41.31AB

Xp [m]	Yp [m]	Botlev [m]	Depth [m]	Setup [m]	Hsig [m]
336500.	3642760.	0.7834	2.8190	0.395523	1.74619
336600.	3642760.	0.8679	2.8998	0.391899	1.81489
336700.	3642760.	0.7753	2.8084	0.393112	1.80410
336800.	3642760.	0.6756	2.7121	0.396453	1.76487
336900.	3642760.	0.5736	2.6144	0.400855	1.71951
337000.	3642760.	0.4779	2.5236	0.405635	1.67813
337100.	3642760.	0.4519	2.5011	0.409163	1.66575
337200.	3642760.	0.4374	2.4896	0.412223	1.66474
337300.	3642760.	0.4309	2.4853	0.414477	1.67191
337400.	3642760.	0.4269	2.4830	0.416125	1.68045
337500.	3642760.	0.4461	2.5027	0.416538	1.69354
337600.	3642760.	0.5110	2.5664	0.415421	1.71731
337700.	3642760.	0.5838	2.6371	0.413328	1.74442
337800.	3642760.	0.6542	2.7048	0.410621	1.77001
337900.	3642760.	0.7222	2.7698	0.407580	1.79274
338000.	3642760.	0.7695	2.8144	0.404878	1.80793

Table 2: Wave setup and height results for the operational condition.

Run:001 Table:A1 SWAN version:41.31AB

Xp [m]	Yp [m]	Botlev [m]	Depth [m]	Setup [m]	Hsig [m]
336500.	3642750.	0.5664	2.4192	0.212751	1.55871
336600.	3642750.	0.6524	2.5029	0.210494	1.63282
336700.	3642750.	0.5668	2.4199	0.213080	1.62214
336800.	3642750.	0.4746	2.3321	0.217511	1.58588
336900.	3642750.	0.3799	2.2426	0.222755	1.54753
337000.	3642750.	0.2902	2.1583	0.228096	1.51370
337100.	3642750.	0.2609	2.1329	0.231993	1.50361
337200.	3642750.	0.2369	2.1127	0.235746	1.49922
337300.	3642750.	0.2225	2.1012	0.238711	1.50183
337400.	3642750.	0.2106	2.0917	0.241111	1.50586
337500.	3642750.	0.2260	2.1080	0.242001	1.51581
337600.	3642750.	0.2962	2.1771	0.240859	1.53783
337700.	3642750.	0.3762	2.2549	0.238682	1.56243
337800.	3642750.	0.4539	2.3299	0.236052	1.58542
337900.	3642750.	0.5292	2.4024	0.233261	1.60728
338000.	3642750.	0.5799	2.4506	0.230696	1.62233

CONCLUSIONS

This study was based on collection of climatic and natural data from several international sources and previous international studies carried out near to the area under study. The prevailing direction of winds and waves is the North-West. From the results of this study on determination of highest sea water level at the proposed locations for the outlet of drainage channel of TRR, it was concluded that the highest effect of sea water level rise is due to storm surge. The effect of astronomical tide, wave setup, and climate change is approximately close. The total effect in the event of extreme marine storm raises

the sea water level to a height of about 2 m above MSL with a probability of occurrence of once every 50 years. The total effect in the event of operational conditions raises the sea water level to a height of about 1 m above MSL with a probability of occurrence of once every 5 years. Since the invert level of the outlet is set at 2.15 m above MSL, this level is considered sufficient under extreme and operational conditions. No occurrence of outlet submergence for all suggested locations even in extreme storm condition. Since the outlet is located at the shore, it is recommended to conduct a technical study to design a shore protection structure against erosion resulting from the impact of waves on the area around the outlet.

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DECLARATION OF CONFLICTING INTERESTS

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The author did not use generative AI or AI-assisted technologies in the preparation of this manuscript.

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