EO Clinic project:

Shoreline Mapping in the Gaza Strip

Work Order Report

Support requested by:
United Nations Development Programme (UNDP)

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ABOUT THIS DOCUMENT

This publication was prepared in the framework of the EO Clinic (Earth Observation Clinic, see below), in partnership between ESA (European Space Agency), the United Nations Development Programme (UNDP) Gaza Office and team of service providers contracted by ESA: EOMAP GmbH & Co. KG (Germany), GeoVille GmbH (Austria).

This Work Order Report (WOR) describes the context of the UNDP activities on Shoreline Mapping in the Gaza Strip, the geoinformation requirements of the activities and finally, the EO products and services delivered by the EO Clinic service providers in support of those activities.

ABOUT THE EO CLINIC

The EO Clinic (Earth Observation Clinic) is an ESA (European Space Agency) initiative to create a rapid-response mechanism for small-scale and exploratory uses of satellite EO information in support of a wide range of International Development projects and activities. The EO Clinic consists of "on-call" technically pre-qualified teams of EO service suppliers and satellite remote sensing experts in ESA member states. These teams are ready to demonstrate the utility of satellite data for the development sector, using their wide range of geospatial data skills and experience with a large variety of satellite data types.

The support teams are ready to meet the short delivery timescales often required by the development sector, targeting a maximum of 3 months from request to solution.

The EO Clinic is also an opportunity to explore more innovative EO products related to developing or improving methodologies for deriving socio-economic and environmental parameters and indicators.

The EO Clinic was launched in March 2019 and is open to support requests by key development banks and agencies during the 2 years project duration.

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ACKNOWLEDGEMENTS

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1 DEVELOPMENT CONTEXT AND BACKGROUND

EOMAP was contracted by United Nations Development Programme (UNDP) to perform a Shoreline Mapping study for the coast of Gaza Strip.

The shoreline of the Gaza Strip has undergone serious changes during the last decades threatening the livelihood of their coastal inhabitants. Several in-water constructions since the 1970 were built in the Gaza Strip and on the Egyptian side of the border without prior studies on the consequences or simply disregarding international conventions requiring international communication between countries (Environmental Justice Atlas 2018). Currents from the southwest transport Nile river sands along the shoreline of Egypt and Gaza delivering a constant stream of sediments (Abualtayef et al. 2013). This alongshore transport has been disturbed and disrupted by sea groins built in the Gaza Strip in 1972, the consecutive construction of the fishing port of Gaza City in 1994 and an Egyptian sea groin built close to the Palestine border in 2010 (Adwan 2016). A very recently finished Israelian sea barrier constructed on the Northern border of Gaza could have future implications for Gaza's shoreline (The Times of Israel 2019).

In order to investigate effects of the constructions on accumulation and erosion along the coast of the Gaza strip and to evaluate and predict impacts on the coastal dynamics for future constructions, EOMAP was contracted to conduct the following study using very high resolution (VHR) satellite imagery between 2010 and 2020 together with high resolution Landsat imagery between 1990 and 2010. In addition, Sentinel-2 data will be analysed quarterly for the time period between 2017 and 2020.

2 PROPOSED WORK LOGIC FOR EO-BASED SOLUTIONS

In this study optical satellite imagery from multiple satellite missions was used to derive shoreline information for the coast of Gaza Strip. An overall number of 29 satellite images between 1990 and 2020 have been processed, using sensors of different native resolutions of 1.5m (SPOT), 2m (Pléiades, WorldView), 10m (Sentinel-2) and 30m (Landsat-5/7).

The workflow to derive shoreline includes the following steps.

1. revision of the geolocation of the satellite data to result in **ideal relative geopositioning**
   In order to improve the relative geolocation accuracy (fit of satellite imagery to each other) we selected those satellite record with the lowest off-nadir recording angle was as reference scene (Quickbird image, recorded on 29st Jan 2010). This scene was determined as the baseline for geolocation correction so that all other scenes have been shifted to fit the geolocation of this scene. Thus, the relative geolocation accuracy is the pixel size of the input data.
2. calculation of the Normalized Difference Water **Index** (NDWI)
   The NDWI is the normalized ratio of green and near-infrared light. These wavelengths have different reflectance properties for land and water surfaces and thus allow a separation between those surfaces.
3. The NDWI is used to define a **land-water-border threshold**
   We applied two approaches to identify the land-water-border threshold. The first one was based on a manual threshold applied by an EO expert. Based on the NDWI imagery, individual thresholds between land and water have been defined by visual inspection and testing for each satellite record. The second approach is an automatic approach developed by Donchyts et al. (2016). It is also based on the NDWI calculation and identifies a threshold for separating land and water by a combination of edge detection and histogram analysis.
4. **vectorizing** the land-water-mask and
   The gridded classification of land and water, was converted into a vector layer to allow a precise definition of the shoreline. Each of the vector shoreline includes information on date of recording and sensor.
5. **post-processing** (cleaning, smoothing) of the vector data.

The basic principle for shoreline mapping from optical satellite imagery is outlined in FIGURE *1*

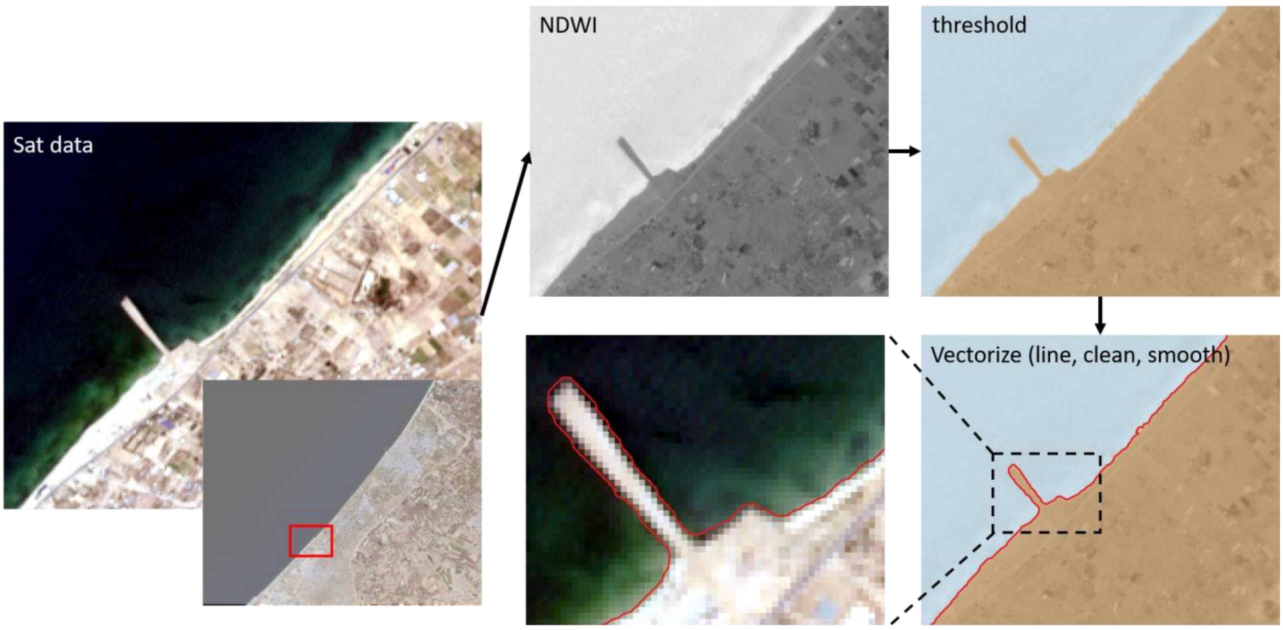

FIGURE 1: Basic workflow for derivation of shoreline vector data from optical satellite imagery

Statistical measures for shoreline dynamics have been derived using the USGS DSAS toolset. The tool enables the calculation of rate-of-change statistics from multiple shoreline positions, establishes measurement locations and interprets the stability of the shoreline.

All results have been provided as line type vector data, as PDF maps for hot-spot regions and furthermore have been ingested into the UNDP Gaza web application (URL: https://www.undp.gaza.eoapp.de/ online accessible until 31st Dec 2020 if not agreed on in a separate contract)

Based upon these analyses, a classification of shoreline stability could be performed and patterns of accumulation and erosion along the coast could be identified and linked to construction works in the past. As currents along the Gaza Strip shoreline usually flow from south-western to north-eastern directions, an accumulation of sediments takes place right in front of the construction (e.g. harbour or sea groin), whereas behind the construction, areas of erosion can be observed.

These findings can serve as valuable information about the impact of future constructions regarding the amount of accumulation and especially erosion, as the latter can pose a danger to livelihood and property of the people of the Gaza Strip living along the coast.

3 DELIVERED EO-BASED PRODUCTS AND SERVICES

3.1 Shoreline Maps

All outputs, which are described in this section have been delivered as vector files (polyline shapefiles) with respective metadata, accompanied by maps of the general results as well as hot spot areas and the web application (URL: https://www.undp.gaza.eoapp.de/). We recommend to explore the use of the web application to explore the outcomes most effectively.

3.1.1 Specifications and results

In order to get a complete coverage of the focus area for all desired years, optical very-high resolution (VHR) data from Pléiades, SPOT-6, WorldView-2 and Quickbird (0.5m-2m pixel resolution) were chosen in addition to Landsat-5/7 (30m pixel resolution) for the early years (1990-2005) of the monitoring period. Quarterly Sentinel-2 records (10m pixel resolution) were used for the derivation of shorelines as an additional source of information for the years 2017-2020 and for a single data in 2015 to fill a data gap.

The data license to the VHR data has been purchased through commercial satellite operating companies, Airbus and DigitalGlobe/Maxar.

The shorelines along Khan Yunis new port derived by the described method is outlined in the following FIGURE 2. The construction of the port into offshore waters beginning in 2014 obviously led to an accumulation to the southwest, whereas to the northeast of the port, a significant shift of the shoreline towards inland, and thus coastal erosion, can be observed. This is a typical pattern that can also be recognized in other places such as the Gaza main port or the sea groin in the southwest beyond the Egyptian border. Therefore, similar effects have to be expected for future constructions.

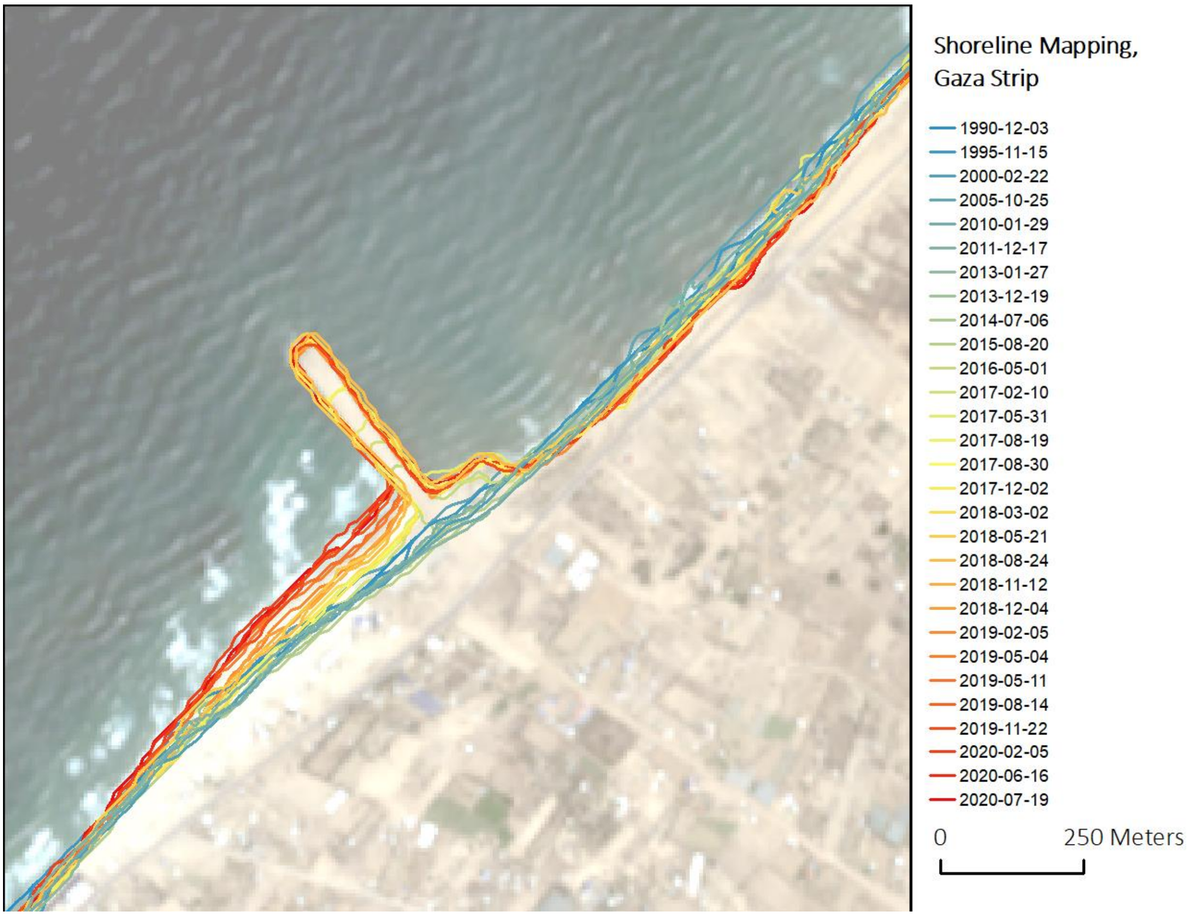

FIGURE 2: Shoreline mapping at Khan Yunis new port from 1990-2020

The data have been delivered as vector files (polyline shapefiles) with respective metadata, accompanied by maps of the general results as well as hot spot areas and the webApp .

3.1.2 Quality Control, Validation and Limitations

In order to improve the geolocation accuracy of the output data, the VHR scene with the lowest off-nadir recording angle was selected as reference scene (Quickbird image, recorded on 29st Jan 2010). This scene was determined as the baseline for geo-location correction so that all other scenes have been shifted to fit the geolocation of this scene. This process results in perfectly matching image datasets. Thus, the **relative geolocation accuracy** is the pixel size of the input data. It is 1.5m to 2m for VHR data, 10m for Sentinel-2 data or 30m for Landsat.

On-site validation data of shoreline positions at different points in time was not accessible during this study. Thus, the **absolute geolocation accuracy** must be seen as the uncertainty of the reference layer, which is stated to be 5m CE90 by the satellite owner.

Satellite data have been recorded on a precise time and data and thus represent the situation at time of satellite image recording and the derived shoreline information represent this snapshot in time. Thus, uncertainties in the shoreline delineation can be introduced by strong changes in water levels at time of satellite recording. However, this limitation is considered to be low, because (a) satellite records have been selected for water conditions with low impact on seastate and (b) the tidal water level changes are low for the Gaza Strip. For the predicted tidal station of Ashdod the difference between mean high water neaps (MHWN) and mean low water neaps (MLWN) datum is only 30cm (accessed through UKHO Admiralty Total Tide).

3.2 Statistical analyses of shoreline changes

We applied the US software DSAS to quantify change rates of the shoreline. The software generates results for transects which are perpendicular to the shoreline and equally spaced along the coast. We defined a spacing of 50m between the single transects. The DSAS tool measures the distance between the shoreline which intersection these transects. The information on the geolocation of the intersection and the date of the shoreline along with uncertainties of the shoreline delineation allow to generate several outputs which quantify the change of the shoreline. These parameters are described below.

- **Net shoreline movement (NSM)**: NSM is the distance between the oldest and the youngest shorelines for each transect; therefore, units are in meters.
- **Weighted linear regression rate of change (WLR)**: A linear regression rate-of-change statistic was determined by fitting a least-squares regression line to all shoreline points for a transect. The more reliable data (less uncertainties) are given greater emphasis or weight towards determining a best-fit line (see FIGURE *3*). The uncertainty is defined by the different spatial resolutions of the satellite data (see also *relative geolocation accuracy*). The unit of the shoreline change rate is meters per year. Several statistical measures are provided together with the WLR: the **standard error of the estimate (WSE)**, the **90% confidence interval (WCI90)** and the **R-squared statistic (WR2)**.

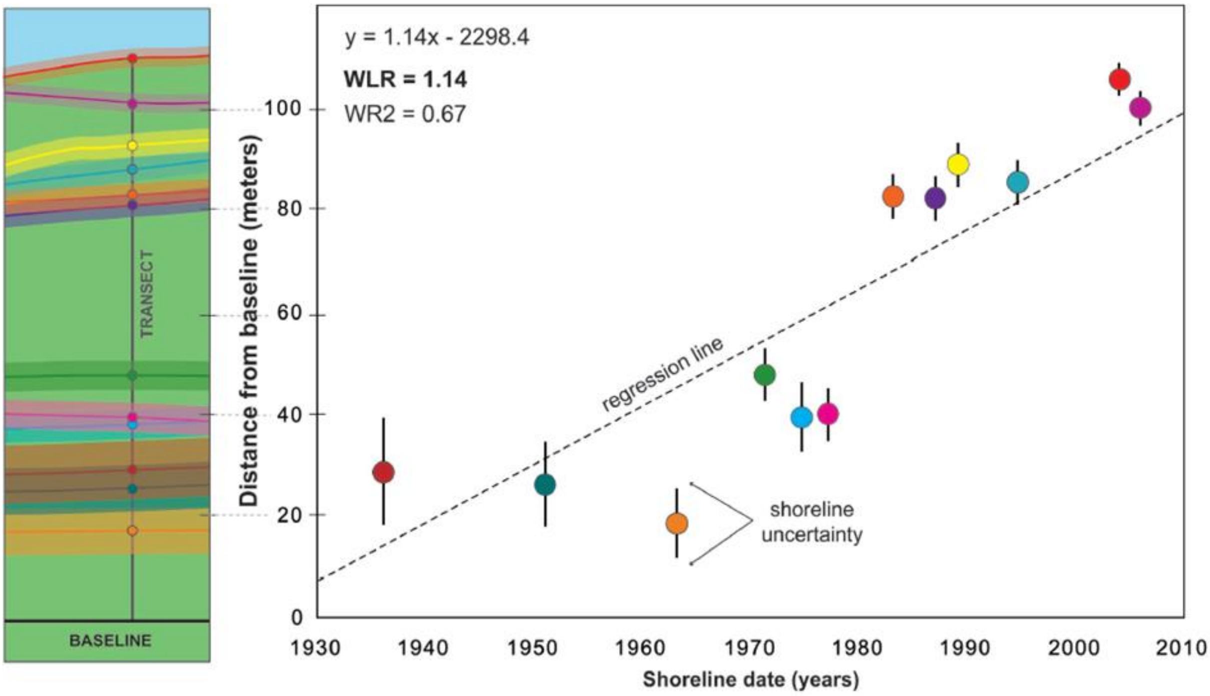

FIGURE 3: A shoreline dataset (baseline [black], transect [gray], and shorelines and intersects [multicolor], with shoreline position uncertainty) to describe how a weighted linear regression is generated. The weighted linear regression rate is determined by plotting the shoreline positions with respect to time. Smaller positional-uncertainty values (shown as vertical bars around each data point in the graph) have more influence in the regression calculation because of the weighting component in the algorithm. The slope of the regression line is the rate (1.14 meters per year). Source: USGS, 2020

The following figures indicate the results of the NSM (FIGURE 4) and WLR (FIGURE 5) parameters at the example of Khan Yunis new port. The calculations show that accumulation of sediments almost reached 90m between the oldest (1990-12-03) and most recent (2020-07-19) shoreline right in front of the construction to the south-west, whereas north-east of the site, the coastline was shifted backwards more than 40m. Accumulation rates reach values of up to almost 10m/year, erosion rates up to -3m/year. Similar developments can be observed at further sites along the coast.

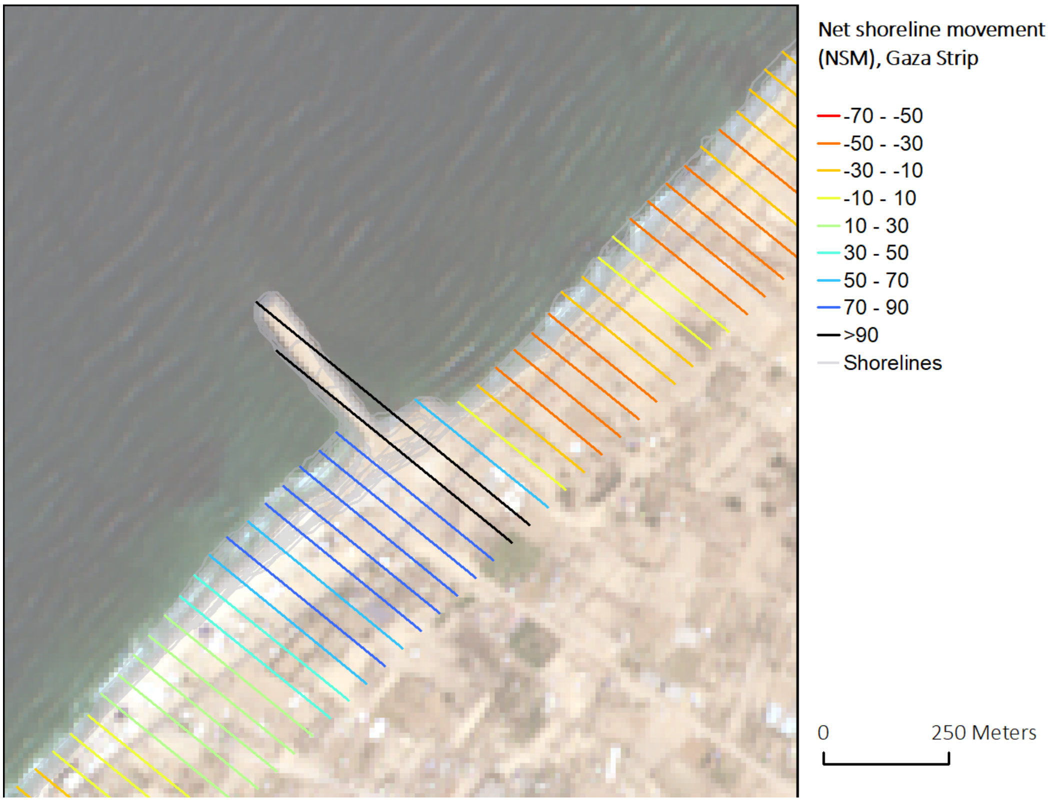

FIGURE 4: NSM parameter at Khan Yunis new port

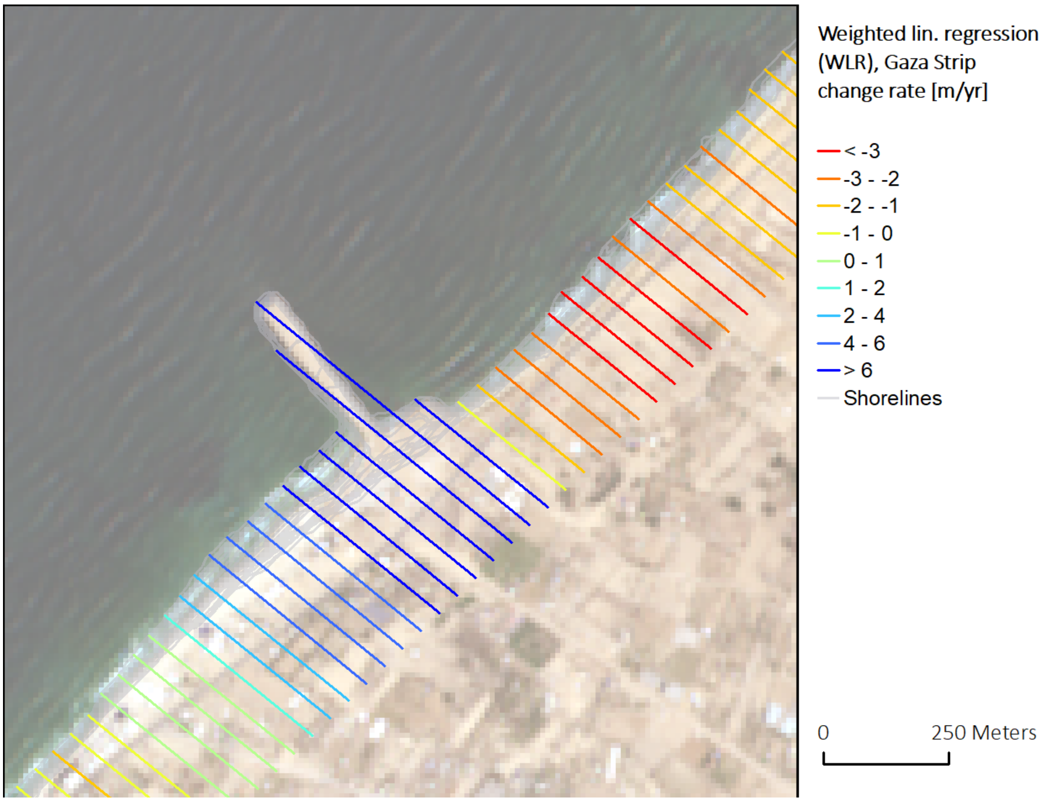

FIGURE 5: WLR parameter at Khan Yunis new port

3.2.1 Quality Control, Validation and Limitations

On-site measurements of shoreline positions over time and space was not available during this study. Thus, we could not perform a verification with local measurements.

We used the statistical performance indicators which were derived from the WLR analysis, which on-its own already included the resolution uncertainties of the input data. The WRL provides important parameters to define the quality of fit, which need to be considered in the interpretation of the results (see section 3.2).

3.3 Shoreline stability classification

Derived from the results above, a shoreline stability classification can be performed based on the thresholds as defined in TABLE 1.

TABLE 1: Classification and statistical thresholds for the shoreline stability classification

Description	Net shoreline movement (NSM):	R-squared statistic (WR2).
stable, no significant change	>-10m and < 10m	< 0.5
significant accumulation	> 10m	> 0.5
significant erosion	< -10m	> 0.5
artificial accumulation (constructions)	-	-

The ‘artificial accumulation’ shorelines were identified by the analyst and represent those areas, where man-made coastal construction has changed the shoreline.

The shoreline classification outcomes are shown in FIGURE 6. It reveals typical patterns of accumulation and erosion caused by constructions reaching into offshore waters.

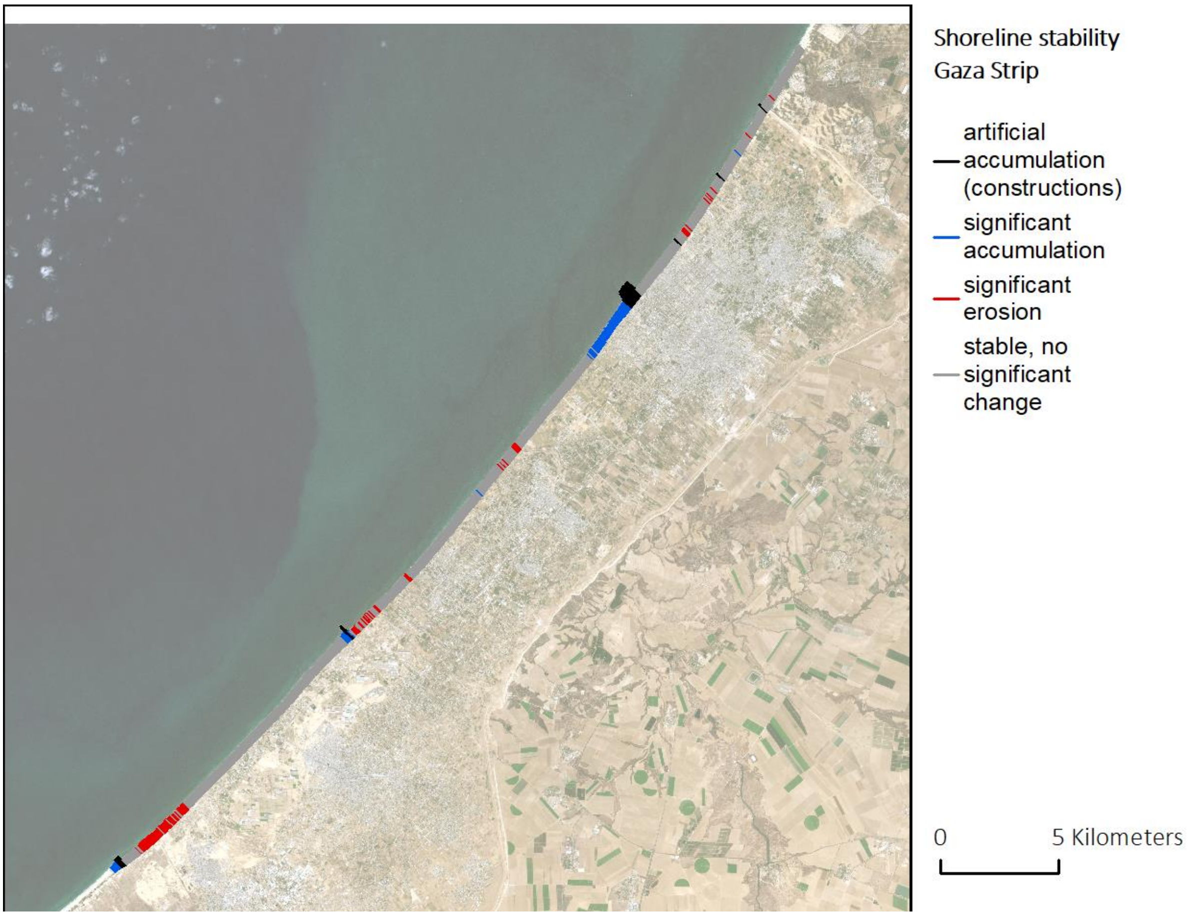

FIGURE 6: Shoreline stability classification for the coast of Gaza Strip

3.4 Additional data layers to support the interpretation on shoreline change

In attrition to the contractually agreed data layers described in sections 3.1 to 0. EOMAP provided demonstration datasets for shallow water bathymetry and ocean currents. These parameters together with the information on sediment loads are crucial information to understand and predict coastal change. This section will briefly describe those layers and further details can be provided on request.

3.4.1 Satellite-Derived Bathymetry

Unlike other survey methods Satellite-Derived Bathymetry (SDB) offers a remote method of surveying shallow water zone. It is based on the concept of using the reflectance intensity of different wavelengths (colours) of the sunlight which is recorded by the satellite sensor. This information in combination with relevant databases and physical models determines the shallow water depth down to the light penetration depth. In the last decade, there has been an increasing update of EOMAP's SDB data and software services. Those data are integrated in nautical charts by UK and NZ hydrographic offices, the European bathymetric grid (EMODnet Bathymetry) and frequently being used by coastal construction entities.

For the Gaza Strip it offers an ideal opportunity to access continuous information on shallow water bathymetry and the historic situation down to water depth of 15m. These datasets can be considered as crucial for coastal planning and of high importance for modelling and predicting coastal change. For that purpose, we have provided Satellite-Derived Bathymetry data for a subset of the Gaza Strip which represent the status on Sept 2015 and Sept 2020 (see FIGURE 7). It becomes obvious, that the change in the shallow water morphology impacts the change in shoreline and thus, it must be seen as a third dimension the shoreline analysis. We recommend to combine this information with hydrodynamic modelling to allow for shoreline predictions (see section 4).

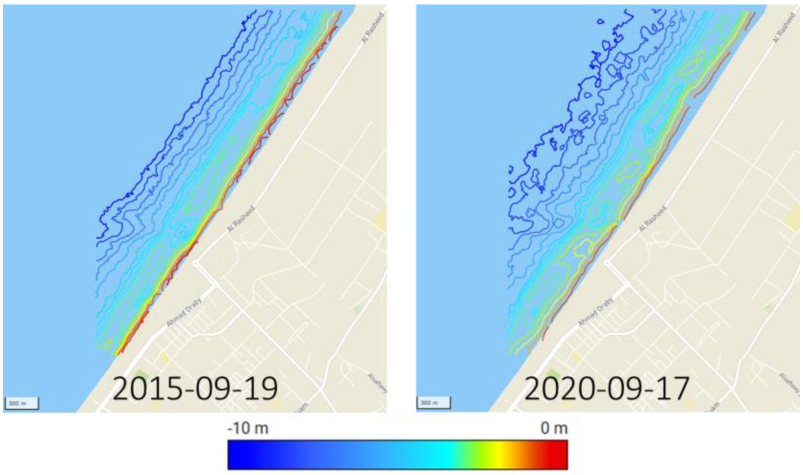

FIGURE 7: Screenshot of the WebApp (URL: https://www.undp.gaza.eoapp.de) showing the provided Satellite-Derived Bathymetry layer for a subset of Gaze. Two dates been analysed.

3.4.2 Ocean Currents

Ocean currents represent another important variable to understand coastal change. We accessed the Mediterranean Forecasting System (Med-Currents, Clementi et al.). It is a coupled hydrodynamic-wave model implemented over the whole Mediterranean Basin. The model horizontal grid resolution is 1/24˚ (ca. 4 km). The hydrodynamics are supplied by the Nucleous for European Modelling of the Ocean (NEMO v3.6) while the wave component is provided by Wave Watch-III; the model solutions are corrected by a variational data assimilation scheme (3DVAR) of temperature and salinity vertical profiles and along track satellite Sea Level Anomaly observations.

We provided the surface currents in a monthly mean for the time series from Jan 2018 to July 2020 (see FIGURE 8).

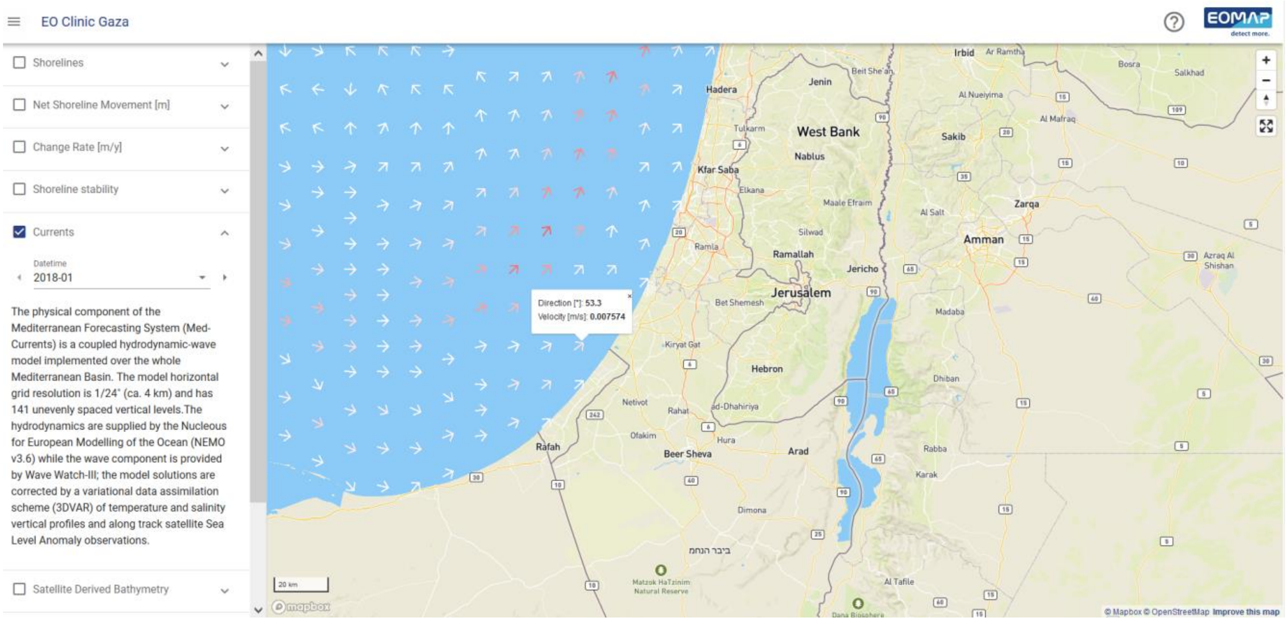

FIGURE 8: Screenshot of the WebApp (URL: https://www.undp.gaza.eoapp.de) showing the average direction and velocity of ocean currents on January 2018.

3.4.3 Water turbidity and sediment loads

We wish to highlight, that sediment transports in the water column can be continuously be mapped and quantified by satellite derived information (see FIGURE 9). Spatial data, such as turbidity and total suspended matter (TSM) can be generated multiple times per week in a dense spatial resolution of 10-30m. These data allow to identify sediment transport, identification of eddies and current streams and also serve as input to hydrodynamic models which aim to predict sediment transport. We have not provided demonstration datasets in this project but would like to highlight global example layers which are accessible through ESA's SDG6 portal (see next figure and URL: http://sdg6-hydrology-tep.eu/) and white paper (URL: https://www.eomap.com/exchange/pdf/HTEP_Information_Booklet_Water_Quality_Monitoring.pdf).

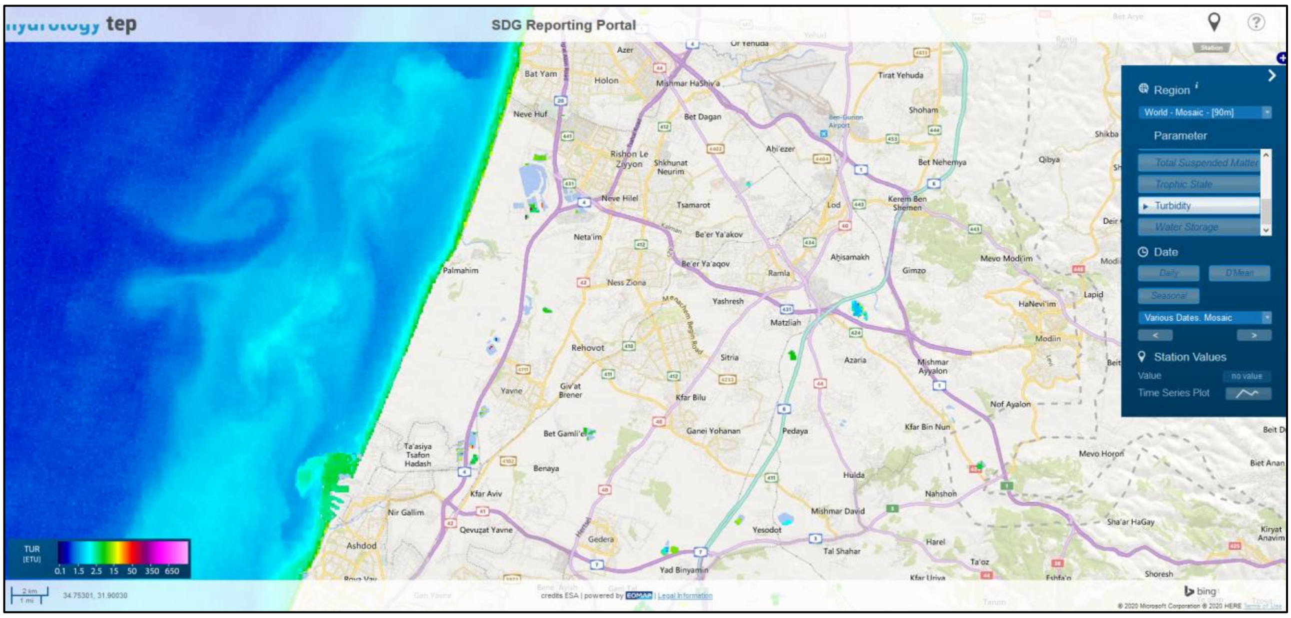

FIGURE 9: Screenshot of the SDG6 portal (URL: *http://sdg6-hydrology-tep.eu/*) showing water column turbidity for a specific date.

3.5 Web GIS

The web GIS (see FIGURE *10* to FIGURE *12*) can be accessed at https://www.undp.gaza.eoapp.de/ and includes all product layers described in sections 3.1 to 0., but also offers additional layers for monthly aggregated sea currents (data source: Copernicus Marine Service) and a subset of EOMAP's Satellite-Derived Bathymetry (SDB) data. The layers can be selected from the list on the left. A short description of the parameter displayed and the colour bar will appear. From the main map, single line features can be selected by left-click. A small pop-up will show up, indicating the values for the selected feature. The date for a single shoreline is displayed by hovering a shoreline feature. A short guide and contact details are provided by clicking the question mark on the top right.

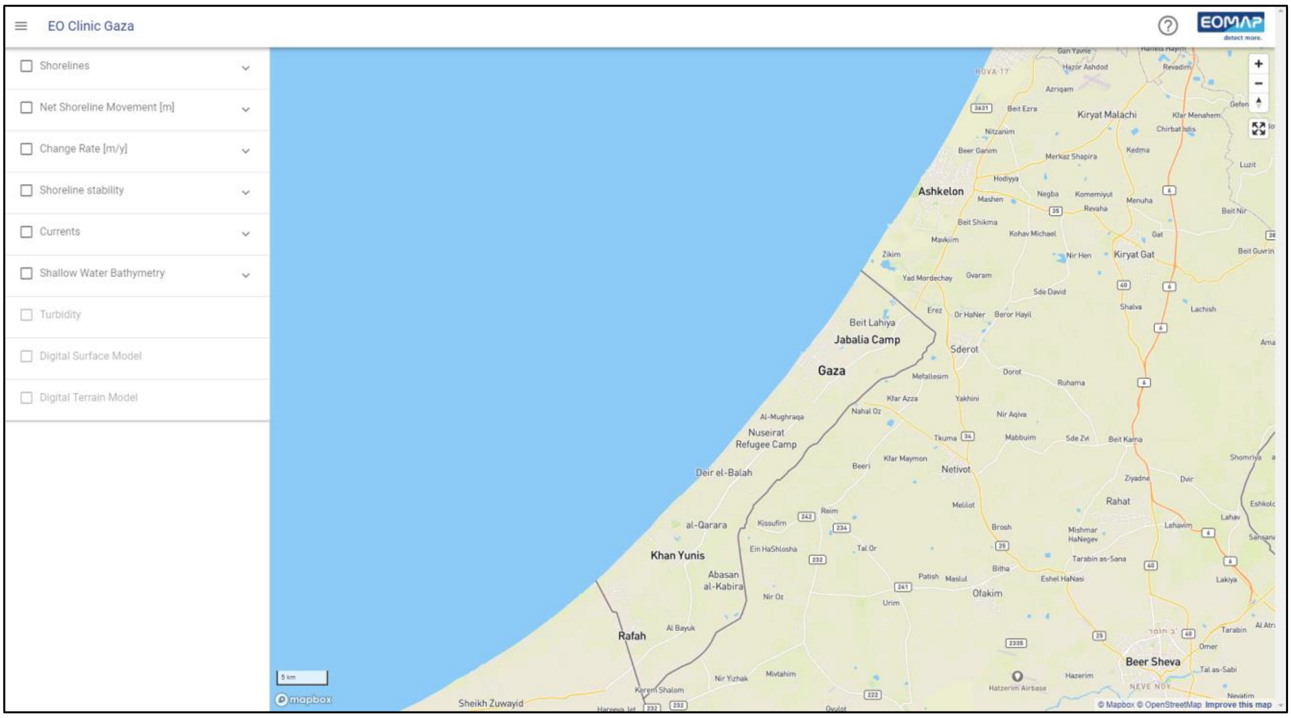

FIGURE 10: Landing page of the WebApp (URL: https://www.undp.gaza.eoapp.de)

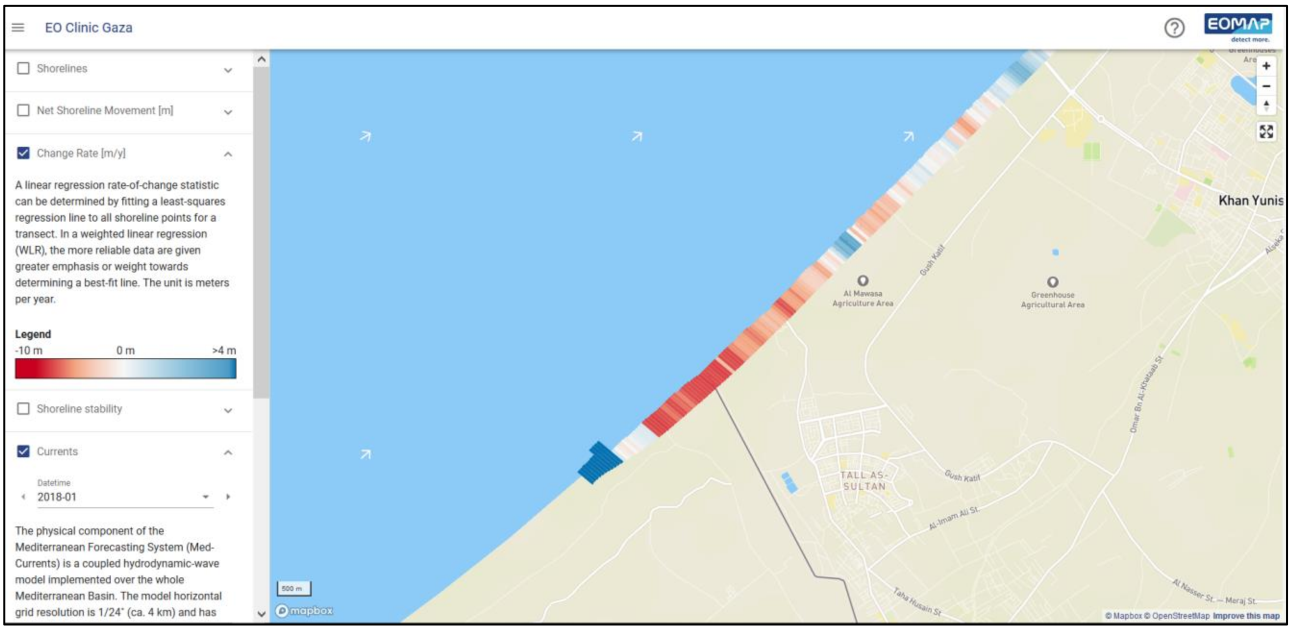

FIGURE 11: Screenshot of the WebApp (URL: https://www.undp.gaza.eoapp.de) showing the coastal change rate and ocean currents.

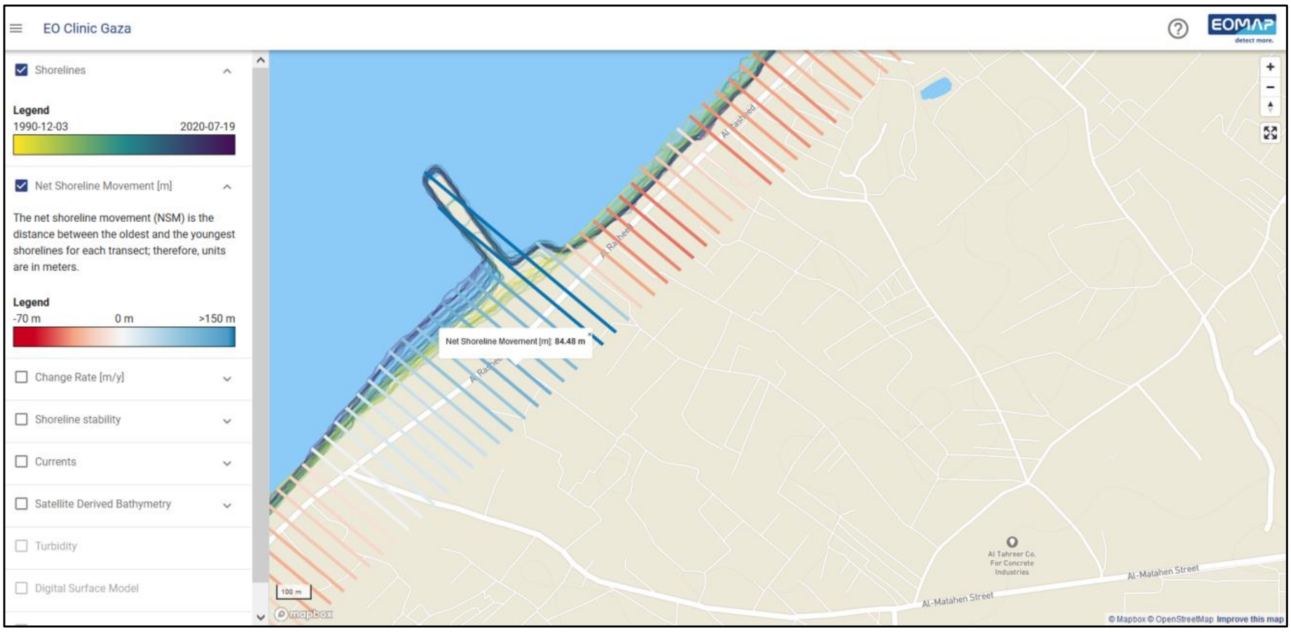

FIGURE 12: Screenshot of the WebApp (URL: https://www.undp.gaza.eoapp.de) showing the net shoreline movement and single shorelines.

4 CONCLUSIONS AND OUTLOOK

In this study we could demonstrate the strength of using satellite data analytics to identify and quantify shoreline stability and change rates of the shorelines for the Gaza Strip. By using a times series from 1995 to 2020 we could identify significant shoreline changes which results in accumulation and erosion processes of up to 70m coastal loss. These data allow to quantify the impact of coastal construction within Gaza and on the Egyptian border on the shoreline. A WebApp was design to visualize and query the outcomes of the data in a most easy and convenient way. The intention of the webapp is to make it accessible to stakeholders and policy makers.

These conclusions imply the recommendation to continuously monitor the Gaza shoreline. We suggest a monthly mapping frequency of the data analytics. The results of the monitoring can be made accessible through the portal and provide immediate access to the information.

For more advanced studies on erosion and accumulation processes we suggest a combination of hydrodynamic modelling and satellite derived information. Typically, the availability to high resolution and recent shallow water bathymetric data and information on sediment transports strongly limits the ability of hydrodynamic models to predict erosion processes. Both of this dataset can be derived from satellite data. EOMAP provided sample data for the Satellite-Derived and demonstration data on water turbidity. Thus, we conclude, that a more in-depth analysis on future trends and planning on coastal construction and protection activities should make use of a combination of hydrodynamic modelling and satellite derived information. It will significantly increase knowledge, while keeping costs at a minimum.

APPENDIX A: ADDITIONAL INFORMATION

TABLE 2 shows a list of satellite images used for this study.

TABLE 2: List of satellite images used

Year	Date(s) of satellite recording	Satellite	Spatial res. (m)	No. of spectral bands
2020	19.07.2020	Sentinel-2	10	12
2020	16.06.2020	SPOT-6	1.5	4
2020	05.02.2020	Sentinel-2	10	12
2019	22.11.2019	Sentinel-2	10	12
2019	14.08.2019	Sentinel-2	10	12
2019	11.05.2019	Sentinel-2	10	12
2019	04.05.2019	SPOT-6	1.5	4
2019	05.02.2019	Sentinel-2	10	12
2018	04.12.2018	Pléiades	0.5	4
2018	12.11.2018	Sentinel-2	10	12
2018	24.08.2018	Sentinel-2	10	12
2018	21.05.2018	Sentinel-2	10	12
2018	02.03.2018	Sentinel-2	10	12
2017	02.12.2017	Sentinel-2	10	12
2017	30.8.2017/30.8.2017/24.8.2017	Pléiades	0.5	4
2017	19.08.2017	Sentinel-2	10	12
2017	31.05.2017	Sentinel-2	10	12
2017	10.02.2017	Sentinel-2	10	12
2016	01.05.2016	Pléiades	0.5	4
2015	20.08.2015	Sentinel-2	10	12
2014	06.07.2014	Pléiades	0.5	4
2013	19.12.2013	SPOT-6	1.5	4
2012	27.01.2013	SPOT-6	1.5	4
2011	17.12.2011/09.11.2011	WorldView-2	0.5	4
2010	29.01.2010	Quickbird	0.6	4
2005	10.11.2005	Landsat-5	30	7
2000	22.02.2000	Landsat-7	30	8
1995	15.11.1995	Landsat-5	30	7

APPENDIX B: REFERENCES

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