REAL-TIME REMOTE MONITORING (RTRM) OF SELECTED WATER QUALITY PARAMETERS IN MARINE ECOSYSTEM USING WIRELESS SENSOR NETWORKS

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ABSTRACT

Water quality perturbations related to anthropogenic disturbances and industry pressures continue to increase in marine ecosystems. Therefore, effective water quality monitoring programs have become critical for the protection of our water resources. However, without accurate, intensive and long-term data acquisition, the health of the water resources cannot be adequately assessed, effective preservation and remediation programs cannot be run, and program success cannot be properly evaluated.

Herein, this research utilized the recent advances in communication and wireless sensors for the purpose of real time remote monitoring (RTRM) of dynamic marine water quality parameters at various spatial and temporal scales. A platform consists of a robust dynamic integration of three different types of sensors; namely biosensors, physical sensors, and chemical sensors were installed at a selected site at the Red Sea Coast (Gulf of Aqaba, near Haqel City). Biological sensor measures dissolved oxygen (DO) which tracks the upwelling of hypoxic bottom water that cause localized fish kills. Physical and chemical sensors measure various water quality parameters such as pH, conductivity, turbidity, and sediment concentration near river bed.

The station was linked with advanced software applications and hardware components that enable wireless, mobile and Internet computing. A two-way transfer and display of data using RTRM technologies was utilized for data processing via specialized web-based visualization software packages.

This setup establishes integrated methodology for mapping and assessing negative environmental externalities provides a useful tool for the design/development/ implementation of an environmental network for the monitoring of a variety of pollutants over time and space and the assessment of environmental quality of ecosystem.

Ultimately, such system improves statistical and mechanistic modeling in monitoring of water quality trends at local, watershed and regional scales for freshwater, estuarine and marine ecosystems. In addition, it enhances rapid (e.g., real-time) detection of hydrologic variability, recognized as a critical need for early warning systems and rapid response to any harmful events.

Keywords: Real-time monitoring, water quality parameters, sensors, cellular networks

Introduction:

Water quality monitoring programs are essential for any effort to produce information in support of coastal conservation and decision-making. Monitoring normally needs to be carried out as cost-effectively as possible relative to the type of information needed (Baban, 1997). Often it is expected that water quality should be shown with high accuracy in all places, in spite of the fact that direct observations can only be done in a limited number of locations (Cooper, 2004). The needs for an effective water quality monitoring programs have become critical for the protection of our water resources. In recent years, recognition of these problems has raised concerns by regulatory agencies tasked with evaluating water resources in attempts to ensure that environmental levels of chemical, biological and physical variables are maintained within established compliance conditions (Bohme, 2006; Hall *et al*., 2007). As a result, more recent monitoring programs have trended toward including continuous data collection by in situ detectors (Thayer *et al*., 2003).

Worldwide many monitoring programs already extensively use in-situ multi-parameter detectors for collection. Separately geographic information systems (GIS) format is frequently used for archiving, mapping, and data visualization in reports. Compared to GIS, RTRMs are the less mature of these technologies, limited by size, initial cost, mechanical robustness, and level of engineering complexity (Auster, 1997; Curtin, Crimmins, Curcio, Benjamin, & Roper, 2005). Thus their use has been limited to research projects in large lakes, reservoirs, or the open ocean (Atkinson & Mabe, 2006; Biddanda *et al*., 2006; Ruberg *et al*., 2005; Yu, Dickey, Bellingham, Manov, & Streitlien, 2002). The cost-effectiveness, relative simplicity, and reliability of the newer generation of RTRM has improved to the point where they can be deployed efficiently from shore or small boats with minimal efforts (Casper *et al*. 2007, 2009; Hains & Kennedy, 2002; Hall *et al*. 2007; Moline *et al*., 2005).

The goals of this research are;

- Monitoring a variety of pollutants over time and space and the assessment of environmental quality of ecosystem.
- Mapping/assessing negative environmental externalities on water quality parameters.
- Enhancing rapid (e.g., real-time) detection of hydrologic variability, recognized as a critical need for early warning systems and rapid response to any harmful events.
- Providing comprehensive datasets of marine ecosystem parameters for the purpose of modeling at various spatial and temporal scales.
- Providing an early warning system for rapid response to any harmful events that may threaten the coast of Red Sea.

Study site

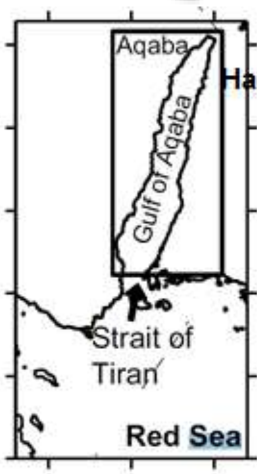
This study was conducted at Haqel City in the Red Sea. Haqel City is located at The Gulf of Aqaba (Figure 1a) which is a semi-enclosed basin that extends over a length of 180 km with a width between 5 and 25 km (average of 16 km). The deepest point in the Gulf reaches 1825 m with an average depth of 800 m. The bathymetry of the Gulf is shown in Figure 1b). Understanding the water quality parameters in the Red Sea is important because of their effects on physical as well as biological conditions along the coast. For example, the Red Sea coast features a diverse array of coral reefs, but that diversity has been reported to be declining in recent decades (Riegl *et al*., 2012). Human impacts can lead to large diurnal swings in water temperature on reefs, with substantial spatial heterogeneity in temperature that is determined in large part by the rate of flushing due to wave induced circulation (Davis *et al*., 2011). Excessively high water temperatures can lead to coral bleaching and mortality (Glynn, 1993).

Materials and methods

The platform includes various sensors to measure multi water quality parameters such as pH, conductivity, turbidity, temperature, and sediment concentration near river bed. A CR1000 datalogger is at the core of each measurement station.

Turbidity measurement with OBS Technology:

The OBS3+ and the OBS300 are used to measure the turbidity. With this method, the probe uses its optics to emit a near-infrared light into the water. It then measures the light that bounces back from the water's suspended particles. If an obstruction is in the emitted light's range, the light will scatter back and the turbidity reading will be too high. The OBS-3+ has optics on the side of its body, which allows you to avoid obstructions above or below the probe. The OBS300 has optics on the end of its body, which allows avoiding obstructions around the sides of the probe (Figure 2).



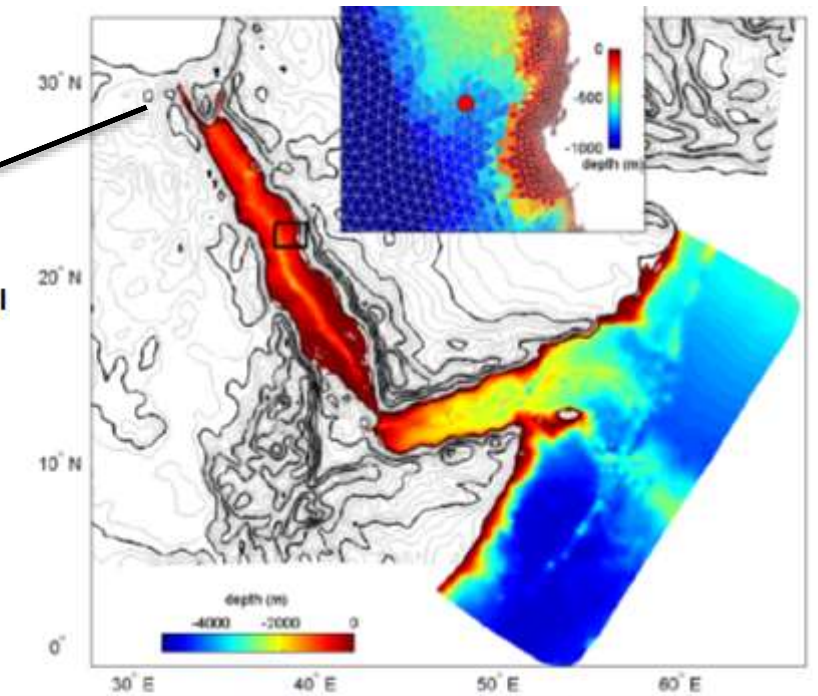


Figure 1a: Study site location

Figure 1b: Red Sea bathymetry

DO sensor

DO is the term used for the measurement of the amount of oxygen dissolved in a unit volume of water. It consists of two electrodes; an anode and cathode which are both immersed in electrolyte (inside the sensor body). An oxygen permeable membrane separates the anode and cathode from the water being measured. Oxygen diffuses across the membrane. It interacts with the sensor's internals to produce an electrical current. Higher pressure allows more oxygen to diffuse across the membrane and more current to be created (Figure 3).

Figure 2: The emitted light and detector cones of the OBS-3+

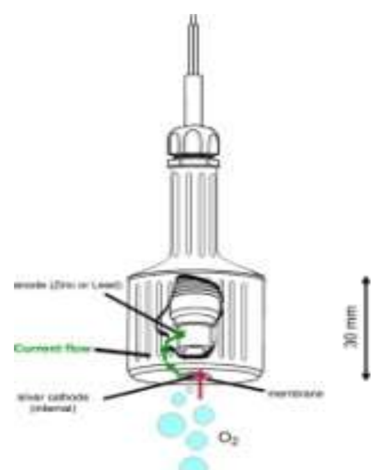


Figure 3: Scheme of the DO sensor

Conductivity and temperature sensors

Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. There are a number of sources of pollutants, which may be signaled by increased EC: Wastewater from sewage treatment plants (point source pollutants; wastewater from septic systems and drain field on-site wastewater treatment and disposal systems (nonpoint source pollutants) Urban runoff from roads.

A probe monitors the electrical conductivity (EC) and temperature of water. EC is measured with three cylindrical stainless steel electrodes mounted in an epoxy housing. Temperature is sensed with a thermistor.

Figure 4: Conductivity and temperature sensors

Data transfer

A two-way transfer and display of data using RTRM technologies was utilized for data processing via specialized web-based visualization software packages. Web-based dissemination of data provided a centralized database for use and detailed data analysis by all water quality stakeholders.

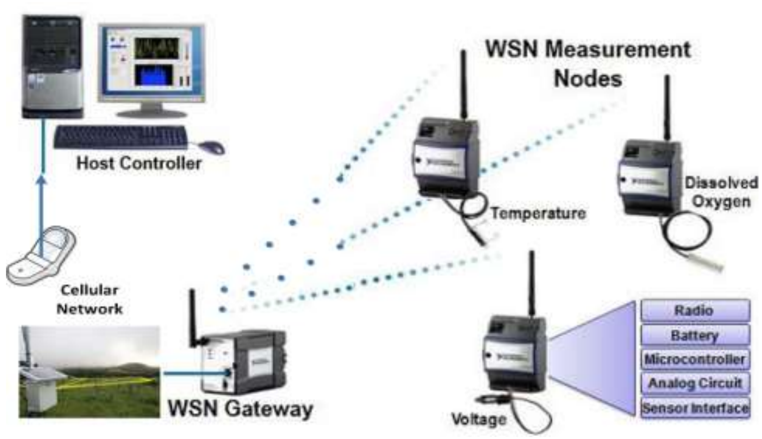


Figure 5: System consists of wireless sensors connected to base station that is connected to a remote desktop through cellular networks.

Results and Discussion

The maps of the area under investigation, generated using measured data are shown in Figures 6-8. These color-coded maps represent a general view of water quality parameters for the Haqel coastal area viable to date, although they only describe the state of water on 19 June 2013.

The dissolved oxygen (DO) levels are above 4 mg/*l* for most of the coastal area considered. These values compare well with typical values (ranging between 4 and 16 mg/*l*) (Pillsbury & Byrne, 2007). The hotspots along the northern coastal stretch, where water depth falls below the critical levels of 2-4 meters display values of about 4-6 mg/*l*.

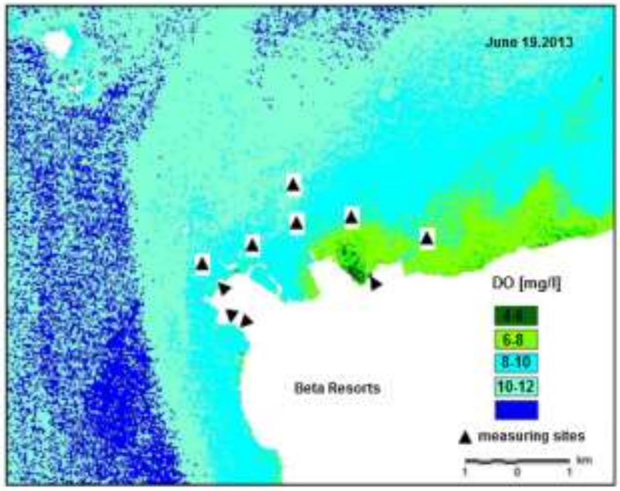


Figure 6: Measured dissolved oxygen levels at Haqel coastal area, Red Sea, as of 19 June 2013.

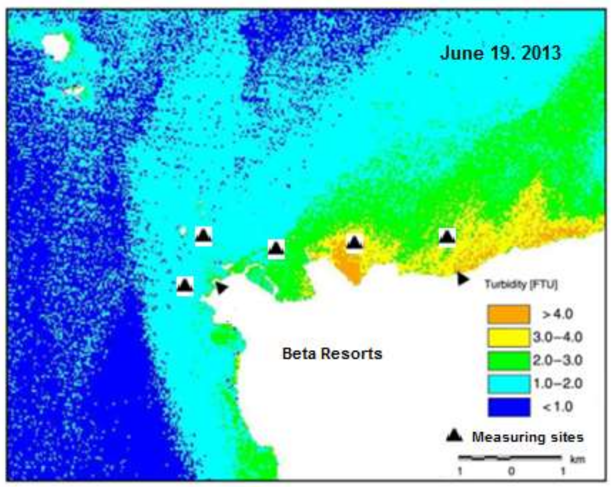


Figure 7: Measured turbidity levels at Haqel coastal area, Red Sea, as of 19 June 2013.

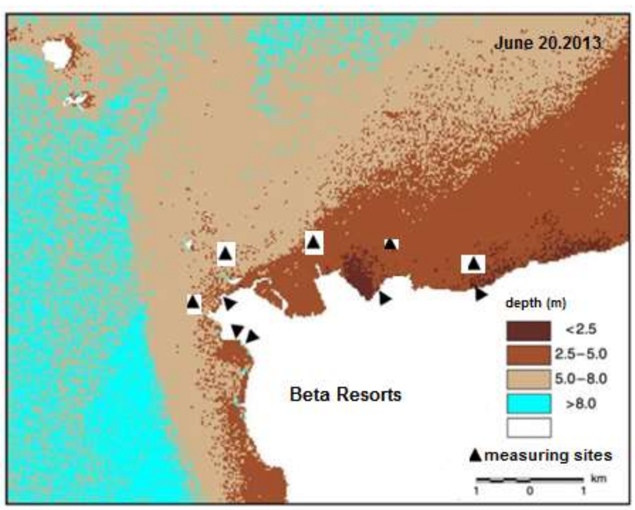


Figure 8: Measured water depths at Haqel coastal area, Red Sea, as of 19 June 2013.

Plumes of turbid waters, where transparency is low, can be observed at several locations nearby to the shoreline, in particular along the eastern coastal stretch. Recreational activities, at various locations, may be at least partly responsible for such conditions.

Conclusion:

Ocean color radiometry of the coast around Haqel indicates that this area is exposed to a moderate risk of developing anthropogenic activities, along most of its shoreline (in particular along the eastern stretch.This appears to be linked to the presence of recreational activities.

The use of robust combination of sensors and cellular networks proved useful for the intended application, which generated a first set data showing the distribution of selected water quality parameters. This information, still to be evaluated at seasonal and annual scales in future studies, will be used to start a national database on water quality for the Saudi coastal environment.

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REFERENCES

1. Atkinson, S. F., & Mabe, J. A. (2006). Near real-time monitoring and mapping of specific conductivity levels across Lake Texoma, USA. Environmental Monitoring and Assessment, 120(1e3), 449e460.
2. Auster, P. J. (1997). ROV technologies and utilization by the science community. Marine Technology Society Journal, 31(3), 72e76.
3. Baban, S.M.J., 1997. Environmental monitoring of estuaries; estimating and mapping various environmental indicators in Breydon Water Estuary, UK, using Landsat TM imagery. Estuarine, Coastal, and Shelf Science 44 (5), 589–598.
4. Biddanda, B. A., Coleman, D. F., Johengen, T. H., Ruberg, S. A., Meadows, G. A., Van Sumeren, H.W., *et al*. (2006). Exploration of a submerged sinkhole ecosystem in Lake Huron. Ecosystems, 9(5), 828e842.
5. Bohme, M. (2006). Distribution of water quality parameters in two cross-sections of the river Elbe measured with high local, temporal, and analytic resolution. Acta Hydrochimica Et Hydrobiologica, 34(3), 201e213.
6. Casper, A. F., Steimle, E. T., Hall, M. L., & Dixon, B. (2009). Combined GIS and ROV technologies improve characterization of water quality in Coastal Rivers of the Gulf of Mexico. In Proceedings of the marine technology Society/IEEE-ocean engineering society conference, Vol. 1e3 (pp. 2555e2563). Biloxi, MS: OCEANS-IEEE, Biloxi, MS.OCT 26e29, 2009.
7. Cooper, D. M. (2004). Some effects of sampling design on water quality estimation in streams. Hydrological Sciences Journal, 49(6), 1055e1080.
8. Curtin, T. B., Crimmins, D. M., Curcio, J., Benjamin, M., & Roper, C. (2005). Autonomous underwater vehicles: trends and transformations. Marine Technology Society Journal, 39(3), 65e75.
9. Davis, K., Lentz, S., Pineda, J., Farrar, J., Starczak, V., Churchill, J., 2011. Observations of the thermal environment on Red Sea platform reefs: a heat budget analysis. Coral Reefs 30, 25–36, doi:10.1007/s00338-011-0740-8.
10. Glenn, S. M., Dickey, T. D., Parker, B., & Boicourt, W. (2000). Long-term real-time coastal ocean observation networks. Oceanography, 13, 24e34.
11. Grunwald, S., Reddy, K. R., Prenger, J. P., & Fisher, M. M. (2007). Modeling of the spatial variability of biogeochemical soil properties in a freshwater ecosystem. Ecological Modelling, 201(3e4), 521e535.
12. Hall, M. L., Conmy, R., Casper, A. F., Coble, P. Steimle, E. T. (2007). Unmanned surface vehicles as environmental monitoring and assessment tools. Proceedings of the Coastal Environmental Sensor Network Annual Meeting, Boston MA.

13. Glynn, P.W., 1993. Coral reef bleaching: ecological perspectives. Coral Reefs 12, 1–17, doi:10.1007/BF00303779.
14. Pillsbury, L. A., & Byrne, R. H. (2007). Spatial and temporal chemical variability in the Hills borough River system. Marine Chemistry, 104(1e2), 4e16.
15. Riegl, B.M., Bruckner, A.W., Rowlands, G.P., Purkis, S.J., Renaud, P., 2012. Red Sea Coral Reef Trajectories over 2 Decades Suggest Increasing Community Homogenization and Decline in Coral Size. PLoS ONE 7, e38396, doi:10.1371/journal.pone.0038396.
16. Ruberg, S., Coleman, D., Johengen, T., Meadows, G., VanSumeren, H., Land, G., *et al*. (2005). Groundwater plume mapping in a submerged sinkhole in Lake Huron. Marine Technology Society Journal, 39, 65e69.
17. Thayer, G. W., McTigue, T. A., Bellmer, R. J., Burrows, F. M., Merkey, D. H., Nickens, A. D., *et al*. (2003). Science-based restoration monitoring of coastal habitats, volume one: A framework for monitoring plans under the estuaries and clean waters Act of 2000 (Public Law 160e457). Series No. 23. In NOAA coastal ocean program decision analysis, Vol. 1. Silver Spring, MD: NOAA National Centers for Coastal Ocean Science. 35 pp. plus appendices.