

Dear Prof. Nunzio Romano,

Please find, in the submission section of the authors, our final response to the comments received from the three reviewers to:

"A review of seawater intrusion in the Nile Delta groundwater system – the basis for assessing impacts due to climate changes and water resources development" (Hydrol. Earth Syst. Sci. Discuss., 10, 10873, 2013).

We value the comments received greatly, as they have pointed out a number of issues to be addressed. We would like to thank the editor and the reviewers for taking time in reading and suggesting modifications to the paper. We highly appreciate it, as the comments have been very useful to improve the paper. We did several modifications to the initial manuscript based on the suggestions of the reviewers. We hope that the editor will find the paper suitable for publication.

We have answered all the comments of the reviewers. Answers are attached to this letter. Along with the answers we are explaining all the changes we have done.

For the ease of reading, we uploaded two versions of the revised manuscript, one with track changes and one with all track changes accepted. We hope that this will be useful for the new review.

Thank you very much for your kind consideration of this resubmitted version of our manuscript.

Sincerely yours,

Marmar Badr

(On behalf of the authors of the manuscript)

Answers to Reviewers Comments

The responses to the individual comments of three reviewers are detailed below.
(Note: Reviewer comments are in italic, authors' responses are in normal text).

The authors would like to thank all of the reviewers for precise and thoughtful comments and constructive criticism which has led to a better manuscript. Below we respond to each referee comments individually. Reviewers please note that figure, table and page numbers refer to figures, table and pages in the uncorrected manuscript.

Response to Anonymous Referee #1:

Comment1:

The manuscript is very poorly written - the text is overly repetitive and exceedingly wordy, there are extensive grammatical issues and a general weakness in the written English. Examples include: P10874: Lines 9-12 - "different" used 4 times in a sentence. Reducing the repeated use of specific words will improve the readability - e.g. P10880 contains numerous accounts of "reported", amongst other examples. Line 18 - "in Nile Delta" should be "in the Nile Delta" Line 25 - "rainfall patterns" is not an impact; there needs to be some characteristic of the rainfall patterns causing an impact (likely it is meant to read "changes in rainfall patterns") P10875: Line 2 - "surface and groundwater" should be "surface water and groundwater" Line 4 - "and are developed rapidly" doesn't make sense in the context of the sentence. Perhaps the authors mean to say "and are being developed at a rapid pace" or "have developed rapidly in recent times". In any case, I don't understand what it means to say that socio-economic resources have developed rapidly, or that natural resources have developed rapidly one might mean that there is a growth in the socio-economics of a region, whereas the other might mean that the natural resources are being increasingly exploited, but neither can be assured from what is written. Line 8 - "of the total agricultural land" needs to have "of Egypt" added to it to be clear about the meaning here. Line 15 - "of the sea level rise" should be "of sea-level rise" Line 17 - comma needed at "unplanned groundwater abstraction, are..." Line 26 - "assure" reads awkwardly here. Lines 28- 29 "nature, not covering the whole" is awkward English - suggest "nature, and do not cover the whole" P10876: Line 2 - "from regional perspective" should be "from a regional perspective". The remainder of the manuscript has a high frequency of these sorts of short-comings (e.g. SEAWAT is misspelt as SEWAT, "seawater" is misspelt as "sweater", "reset" should be "recent", "SI" is introduced part way through the paper as an acronym for "groundwater salt intrusion" when all of the text leading to that point refers to seawater intrusion without an acronym) indicate that a thorough proof-read has not been undertaken.

Authors' answer:

The authors would like to thank deeply the reviewer for his time and effort. The examples given to illustrate his point of view have been corrected. The English structure and grammar of the manuscript has been thoroughly reviewed through a specialized English editing office for proof reading. Repetitive words and concepts have been removed and the paragraphs have been summarized. We hope that the current version of the manuscript has been improved in readability and focuses more on the research goal.

Comment 2:

The referencing is incorrect, incomplete and not properly applied. Examples include: P10993 Line 9 (and elsewhere) - Here and elsewhere, a paper by Werner et al. (2012) is referred to and listed in the reference list as the Groundwater journal paper on vulnerability indicators. The

problem here is that they are referring to the Werner et al. (2013) Advances in Water Resources paper. P10875 L23 to P10876 L2

Authors' answer:

Thank you for pointing out that mistake. We checked and noticed that it is a typing mistake. The whole reference list has been thoroughly revised and corrected. We have made the proper corrections in the new version of the manuscript.

Comment 3:

Table 2 is copy-and-pasted from another paper without modification or permission. On P10883, the table is then wrongly referred to as Table 1. Taking the work of others and inserting into new papers without obtained proper permission is a practice that needs to be avoided, and I implore HESS to offer guidance to the authors on this issue. The table also refers to the wrong reference - i.e. the table is not from the reference that it cites.

Authors' answer:

The authors would like to apologize for the wrong referencing of the table. The whole table has been deleted and the idea of the table has been embedded in the manuscript with the correct reference.

Comment 4:

There are several statements that are incorrect, possibly due to English issues but in some cases there seems to be misguided concepts being suggested. Examples include: P10874 L6 - The salinization of "all coastal land" in the Nile Delta is simply not possible. P10878 L24 - "quantification of such impacts is lacking" (referring to SLR impacts on SWI) is not true. Sherif and Singh (1999) have attempted to quantify SWI from SLR in the Nile Delta. Werner and Simmons (2009) study the general case of SLR impacts on SWI, amongst other subsequent papers which offer a broader range of cases. A recent Nature paper by Ferguson and Gleeson also comments on the topic of SLR impacts on SWI and compare it to pumping impacts - highly relevant to the current investigation. P10879 L1-3 - This statement is untrue "Studies showing the degree of climate change and sea level rise impact on seawater intrusion compared to other factors such as development-induced groundwater abstraction do not exist" – there are several studies that explore this topic - Ferguson and Gleeson (Nature Climate Change), Werner et al. (Groundwater, 2012). P10884 L21-22 - This statement doesn't make sense "...stated that SEAWAT code is accurate and consequently can be used to represent hydrodynamic surface-water flow..." - there is no link between a model's accuracy and its capacity to simulate surface water flow. In any case, SEAWAT does not simulate surface water flows. P10890 L12-13 - 3D models of seawater intrusion are most certainly not capable of assessing "all potential threats of salinization of the whole Nile Delta aquifer". A SWI model is useful for assessing SWI. If agricultural salinization is an issue, then a different model is needed, mostly likely that incorporates unsaturated zone processes.

Authors' answer:

We have revised the manuscript and corrected the misleading statements. We would like also to highlight that the review paper is only concerned with the research that has been done in the Nile Delta e.g. Sherif and Singh (1999) rather than worldwide. We hope that the current version of the manuscript has been improved in readability.

Comment 5:

Much of the text is dedicating to making statements that are entirely obvious to those working in the specialisation of the manuscript. P10881 L27-29 is one example - "However, these hydrological data should be always monitored and updated in order to be integrated in groundwater modeling and give reliable findings", amongst many others. It is a significant weakness in the manuscript to have to wade through all of these obvious statements, which are offered as advice as though they are new ideas. The manuscript can be reduced to 25% of its current length by removing these.

Authors' answer:

The manuscript has been thoroughly proof read. The text that indicates obvious statements similar to the given example has been removed. The authors appreciate the instructions given by the reviewer. Following these instructions we hope that the readability of the new version of the manuscript has been greatly improved. However, it needs to be noted that in Egypt, continuous monitoring for groundwater wells is a persistent problem. There is a great gap in data series which is also reflected in the quality of modelling results. That is the reason behind highlighting this issue in the manuscript (to assure its importance).

Comment 6:

Finally, and perhaps most importantly, the Conclusion to go to 3D modelling is misguided. The idea that a large 3D model will resolve a significant number of issues that others have been unable to overcome requires further consideration. Such a model will require a coarse level of discretisation due to the size of the study area and hence run-times will be extensive. A 3D model of seawater intrusion of this large area will be very unwieldy, and not allow the best use of the available data because it will be entirely un-calibratable, at least using current and widely applied techniques. The coarse discretisation will not allow for accurate prediction of salinity at specific sites, and will be only a "regionally accurate" predictor, at best, providing a very rough overview of possible movements in the wedge. Simpler models will be easier to construct and run and are more likely to allow for improved insight into the study area - i.e. because a large number of parameters can be assessed and feedback from the modelling process comes sooner. Critically, the accumulation of all available information into a working conceptualisation, and the associated "back of the envelope calculations (water balance, steady-state heads and sharp-interface position) will likely provide significantly more insightful management inputs than labouring to develop a large 3D model. A range of tools is needed to properly understand the Nile Delta's groundwater system. There is no silver bullet here. Prevailing wisdom would suggest that one ought to apply the simplest available methods of analysis and prediction in the first instance, and add complexity as the management questions require them. Following on from this, a DSS of the Nile Delta will require a host of modelling applications to allow for the range of issues in the region to be considered and compared, and linked to socio-economic factors. Hence, investing heavily in a 3D simulator, when simpler and less resource intensive methods will provide perhaps accurate-enough estimates and allow for the expenditure of resources on other aspects e.g. surface water processes, data collection, socio-economic factors, agricultural practices, etc., seems misguided, and potentially leading to a considerable waste of resources, given the "all eggs in one basket" notion of building such a model. The idea that is being offered here that a 3D model of seawater intrusion is the best use of limited available resources for management the Nile Delta system is very difficult to defend, and in my opinion, inappropriate.

Authors' answer:

The authors would like to thank the reviewer for pointing out this important issue. Indeed, the authors agree with the reviewer that the coarse discretisation will not allow for accurate prediction of salinity at specific sites. However, this approach will give a regional perspective for the freshwater and saline water interface. This interface has a significant importance in determining the most vulnerable area for future abstraction in Nile Delta aquifer. Of course, a range of tools is needed to identify the characteristic of Nile Delta aquifer properly. We appreciate your suggestion to construct and run simpler models to have improved insight of the salinity in different governorates in Nile Delta. The 3D model can then be used in conjunction with other models. Therefore in the last section, which recommends a 3D model of seawater intrusion as a best tool to manage Nile Delta aquifer we have introduced some modifications by which we introduce this to be **one of the tools** that could be used to determine the vulnerable areas to salinization in the Nile Delta aquifer.

Response to Anonymous Referee #2:

General Comments:

In the paper many topics are treated, like climate change, aquifer properties, previous large scale aquifer model, groundwater local models, etc., but all of them in a quite superficial way and on the basis of a limited literature review. The paper seems more appropriate for a technical conference and could be of some utility for local engineers, physicist and agronomist involved with Nile delta action planning.

Authors' answer:

We highly appreciate the reviewer comment regarding the utility of the research review paper. Indeed, the review paper focuses on a specific national study area. It compiles the most recent work that has been done in seawater intrusion modelling in the Nile Delta only. There are many researches that have been done worldwide in seawater intrusion topic; however, this is out of the scope of that research paper. The objective of the review is to discover the gap and obstacles faced by researchers in that specific region. Nevertheless, Nile Delta in Egypt is very similar to other deltas all over the world and the results of the 3 dimensional modelling applied in Nile Delta could serve as an example to be generally executed in comparable delta. Since the problems that Nile Delta faced nowadays will very likely be future problems encountered in other deltas elsewhere in the world.

Specific Comment

Finally, the main reason of paper inadequacy is in the final Authors' idea on future research activity from Nile delta aquifer coming from their context analysis. They suggest the use of a 3D, unsteady state, variable density computation for large scale modeling of the groundwater. Some details are also given on the possible cell dimension of the model, 1-2 Km length in plane and of the order of meters in the vertical direction. The idea of using a model like SEAWAT with such a computational grid and for long time simulation comes from a lack in experience in the use of such models. I was hardly capable of performing a field scale hydrodynamic simulation on salt wedge intrusion in the groundwater below an industrial area in presence of a pump and treat. Model stability was obtained only by adopting a refined grid (1 .5 million cells, with a length to height ratio of 10 to 1, and very small time steps, of fractions of second). As a consequence of the small time step necessary for computation, a steady state constant density model was used, for the prediction of field scale contaminant transport. The presence of the salt wedge was neglected and only the seafront boundary conditions were changed to take into account the presence of the salt layer. I am reasonably sure that with the length to height ratio of the grid cell proposed by the Authors the model will crash. But even in presence of a very stable solver, the computational time required by the model is prohibitive even for simulating few minutes of groundwater movement.

Authors' answer:

Thank you for pointing out this important issue. The authors totally agree with the reviewer that the Nile Delta is a large computational area to be modelled with SEAWAT. However, the authors are confident that with careful selection of the discretization and numerical parameters in SEAWAT, a regional 3D model for the Nile Delta aquifer can be developed, as has already been demonstrated by some researchers in recently reported studies from other parts of the world (see below). In fact, we have

already successfully developed such a SEAWAT model for the Nile Delta aquifer. After calibration of this model we are hoping to present the results in a separate paper. This approach was in fact partly motivated by a number of research studies in which 3D modelling was successfully used in a large computational area and the models proved to give promising results, e.g. Oude Essink et.al (2010) who used MOCDENS3D to simulate the coastal lowlands of the Netherlands. They calculated the possible impacts of future sea level rise, land subsidence, changes in recharge, autonomous salinization, and the effects of two mitigation countermeasures with a three - dimensional numerical model for variable density groundwater flow and coupled solute transport. Other related references are listed below (and now included in the revised article).

Faneca Sánchez, M., Gunnink, J., van Baaren, E.S., Oude Essink, G.H.P., Elderhorst, W., de Louw, P.G.B., Siemon, B., Auken, E. 2012. Modelling climate change effects on a Dutch coastal groundwater system using airborne Electro Magnetic measurements, *Hydrol. Earth Syst. Sci.*, 16, 4499-4516, doi:10.5194/hess-16-4499-2012.

Oude Essink, G.H.P., E.S. van Baaren, and P.G.B. de Louw. 2010. Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands, *Water Resour. Res.*, 46, W00F04, doi:10.1029/2009WR008719.

Cobaner, M., Yurtal, R., Dogan, A., & Motz, L. H. (2012). Three dimensional simulation of seawater intrusion in coastal aquifers: A case study in the Goksu Deltaic Plain. *Journal of Hydrology*, 464-465, 262–280. doi:10.1016/j.jhydrol.2012.07.022

Response to Anonymous Referee #3:

General Comments:

The paper by Mabrouk et al. compiles numerous studies of the Nile delta groundwater system. The authors evaluate state of the art and suggest modelling efforts that would lead to a comprehensive understanding of the current and future evolution of the delta aquifer, focusing on seawater intrusion issue. I found the paper well-structured and quite clear. Numerous reference about the Nile delta are compiled, especially a number of university works, which are often difficult to know and access. Particularly useful is table 1 that reports hydraulic parameters available for the Nile delta aquifer. Overall, I found that the review, which aims to provide the basis for further avenues of research, is too superficial. The authors repeatedly point out that previous studies on groundwater salinization in the Nile delta were too much local and did not take into account either sea level rise, Nile flow changes, spatial heterogeneity of the aquifer, or groundwater abstractions impacts. However, in my view, recommendations simply suggest that further research should, obviously, take into account those parameters. Although I am not working in the specialisation of the manuscript modelisation of coastal aquifer, I found that the feasibility of the three-dimensional groundwater modelling of the Nile delta aquifer, which intend to integrate both internal parameters (hydrologic and geologic), external forcing (sea level, Nile flow, abstractions), socio-economic changes, and adaptation and mitigation measures, need much further details, critics and discussion.

Authors' answer:

We would like to thank the reviewer for the positive evaluation of the work and for encouragements. We highly appreciate it, as well as we do find the comments very useful to improve the paper. As per the reviewer advice, we have extended the recommendation section to include more details, descriptions and feasibility of the three-dimensional groundwater modelling of the Nile delta aquifer.

Specific Comments

Comment 1: *The paper assesses that sea level rise, Nile River flows changes and groundwater abstraction is the main external factors that would force the evolution of groundwater salinization in the northern delta. Additionally, I suggest that subsidence processes are also a very important forcing of relative sea level changes in deltaic areas, especially in the Nile delta (e.g. Marriner et al., 2012). Furthermore, Psimoulis et al. (2006) demonstrated that the Thessaloniki plain (Greece), composed by deltaic and fluvial sediments, has subsided in the last 50 years up to 3.5 m, resulting from hydro compaction due to intense pumping superimposed on the plain-wide subsidence. Given that increasing groundwater abstractions has occurred in the Nile delta, as demonstrated in the paper (fig. 3), subsidence processes should be discussed in the paper. Lastly, seawater intrusion may also be induced by the retreat of the Nile delta shoreline. Since the construction of the Aswan High Dam and development of a very dense irrigation network in the delta, a sharp decline in the sediment load reaching the Nile coast has been recorded. This favors marine ingression at the Nile coast and may impact the position of the transition zone between seawater and freshwater.*

Marriner, N., Flaux, C., Kaniewski, D., Morhange, 2012. The Nile delta's sinking past: Quantifiable links with Holocene compaction and climate-driven changes in sediment supply? Geology 40(12), 1083-1086. Psimoulis, P., Ghilardi, M., Fouache, E., Stiros S., 2006. Subsidence and evolution of the Thessaloniki plain, Greece, based on historical leveling and GPS data. Engineering Geology 90, 55-70.

Authors' answer:

Indeed, subsidence processes and the retreat of the Nile Delta shoreline are very important forcing of relative sea level changes in deltaic areas. However, we are focused more in this review about the relation between the impact of human development activities represented by excessive abstraction compared to climate change impacts e.g. sea level rise. This is a step forward for further developing a model taking into consideration these two main factors and analyzing their effect. We consider subsidence an important topic, but it is not within the scope of this article. Similarly, the sediment load reaching the Nile coast especially after Aswan Dam construction is also a rich subject for research and a specific, separate review paper is likely needed to discuss its different aspects in details.

Comment 2: The paper evidences the complexity to model properly the whole Nile delta aquifer, because it must include a number of hydraulic and geologic parameters which are only poorly constrained through the available dataset. However, recommendations made by the authors mostly provide a series of obvious statements which could be summarize as: "the most complete dataset you have, the best model you will be able to draw". It is evidenced, for example, in the repetition throughout the manuscript of a call for the need of extensive and continue wells data monitoring: - P 10881, l. 26-28, these hydrological data should be always monitored and updated in order to be integrated in groundwater modeling and give reliable findings - P 10883, l. 1-2, and it is severely impaired by the lack of continuous monitoring data. - P 10883, l. 4-5, accompanied with continuous monitoring. - P 10890, l. 23, Continuous monitoring of data from all wells is also needed, - P 10890, l. 28-29 and P10891, l. 1, A continuous and comprehensive monitoring system of all groundwater data integrated with existing monitoring network of meteorological and hydrological data is therefore crucial challenge for the future. - P10891, l. 20-23, the adaptation and mitigation measures need to be analyzed within an integrated regional plan accompanied with effective monitoring, evaluation and assessment system. - P 10892, l. 14-15, Strict monitoring and assessment strategy should be incorporated as a separate component of the DSS to be used by the authorities.

Authors' answer:

We agree to the repetition of the idea related to the continuous monitoring. The repetition throughout the manuscript has been deleted and rewritten in a more summarized structure.

Comment 3: The authors recommend the use of SEAWAT, regarding the fact that it is the most popular code used in recent years (P 10883, l. 20). This statement is followed by a series of SEAWAT applications. However, it is not argued why others models presented in table 2 (P. 10906) would not be adapted to the Nile delta aquifer. Consequently, table 2 is not useful in our view and section 4 ("brief overview of available models", P10883) is improperly named.

Authors' answer:

The importance of table 2 in the review is to give the reader a brief description of all different models that could be used to model seawater intrusion. However, not all of them are suitable for Nile Delta aquifer. As per the reviewer advice, table 2 has been deleted and section 4 has been rewritten to better represent a brief overview of the available models. We did several modifications to the initial manuscript based on that suggestion of reviewer 1 and we hope the newer version shows more focus to the goal.

Short and technical remarks

- P 10877, l. 21-23, see also Sivitsky et al., 2009. Syvitski, J.P.M., Kettner, A.J. Overeem, I., Hutton, E.W.H., Hannon, M.T., Brakenridge, G.R., Day, J., Vřrřsmarty, C., Saito, Y., Giosan, L., and Nicholls, R.J., 2009, *Sinking deltas due to human activities: Nature Geoscience*, v. 2, p. 681–686.

Authors' answer:

This valuable reference has been added.

- P 10877, l.26-27, *"In their studies they used different climate models to predict sea level rise." Stanley (1990) and Emery (1988) have not used climate models. Sea level rise estimation by these authors was respectively based upon bio-sedimentological indicators and tide gauge data.*

Authors' answer:

Correction has been made accordingly.

- P 10878, l.1, *"The most common estimate that is repeated in many reviews is 60 cm (Essink and Kleef, 1993)." Isn't there a more recent review? The recent report of the IPCC (2013) may update this estimate.*

Authors' answer:

Correction has been made accordingly.

- P 10878, l. 23-24, *"The above mentioned climate change studies also identify the impact of sea level rise on increased seawater intrusion", appears to contradict the following statement (P 10885, l. 17-20): "Given that the potential sea level rise impact on salinization of the Nile Delta aquifer have been only recently recognized, most of the developed variable density models in the past were focused on determining the impact of increased groundwater abstractions on the salinization of the aquifer."*

Authors' answer:

The authors would like to thank reviewer for pointing out this unclear statement that caused misleading understanding. The phrase has been modified according to the reviewer suggestion.

- P 10878, l.25-29, *"In the Nile Delta, extensive groundwater abstraction is also a very significant factor that increases seawater intrusion." Kotb et al. (2000) added that the recycling of sewage water have engendered soil salinization in the northern delta.*

Authors' answer:

The recommended phrase has been added accordingly.

- P 10882, l. 16-18, *"He found that the groundwater heads were increasing during this period and he attributed that to the construction of High Aswan Dam." Because perennial freshwaters were delivered to the delta throughout the whole year? Please specify.*

Authors' answer:

The statement has been rewritten with more clarity and specification.

- P 10882, l.14-15[~] a, *"He mentioned that from 1957 till 1984, the water salinity records showed that it was enhanced and the freshwater was dominating and overcoming seawater intrusion." Does "it" refer to canals level? Please clarify.*

Authors' answer:

The statement has been rewritten with more clarity.

- P 10885, l.11-15, "in case of the Nile Delta the transition zone is relatively large." A map showing the transition area and location of wells in which salinity measurements were made could be useful, as this transition zone dynamic is the main topic of the paper.

Authors' answer:

Thank you, as per the reviewer suggestion a map showing an example of the transition area of the Nile Delta is added. We have referred to the Sherif et.al 2012 as the most recent work that showed the transition zone clearly. However, the salinity wells' observations for each research in the literature review is different in wells' location.

- Figures 1 and 2, depth unity must be mentioned.

Authors' answer:

Depth unit has been added to the figures.