(ATINER)

Athens Journal of Sciences

(ATINER)

Volume 7, Issue 4, December 2020
Articles

ATHENS INSTITUTE FOR EDUCATION AND RESEARCH
A World Association of Academics and Researchers
8 Valaoritou Str., Kolonaki, 10671 Athens, Greece.
Tel.: 210-36.34.210 Fax: 210-36.34.209
Email: info@atiner.gr URL: www.atiner.gr
(ATINER) **Established in 1995** *(ATINER)*

Mission

ATINER is an Athens-based World Association of Academics and Researchers based in Athens. ATINER is an independent and non-profit **Association** with a **Mission** to become a forum where Academics and Researchers from all over the world can meet in Athens, exchange ideas on their research and discuss future developments in their disciplines, **as well as engage with professionals from other fields**. Athens was chosen because of its long history of academic gatherings, which go back thousands of years to *Plato's Academy* and *Aristotle's Lyceum*. Both these historic places are within walking distance from ATINER's downtown offices. Since antiquity, Athens was an open city. In the words of Pericles, **Athens"*...is open to the world, we never expel a foreigner from learning or seeing*". (**"Pericles' Funeral Oration", in Thucydides, *The History of the Peloponnesian War*). It is ATINER's **mission** to revive the glory of Ancient Athens by inviting the World Academic Community to the city, to learn from each other in an environment of freedom and respect for other people's opinions and beliefs. After all, the free expression of one's opinion formed the basis for the development of democracy, and Athens was its cradle. As it turned out, the Golden Age of Athens was in fact, the Golden Age of the Western Civilization. *Education* and *(Re)searching* for the 'truth' are the pillars of any free (democratic) society. This is the reason why *Education* and *Research* are the two core words in ATINER's name.

The Athens Journal of Sciences
ISSN NUMBER: 2241-8466- DOI: 10.30958/ajs
Volume 7, Issue 4, December 2020
Download the entire issue (PDF)

Athens Journal of Sciences
Editorial and Reviewers' Board

President's Message

All ATINER's publications including its e-journals are open access without any costs (submission, processing, publishing, open access paid by authors, open access paid by readers etc.) and is independent of presentations at any of the many small events (conferences, symposiums, forums, colloquiums, courses, roundtable discussions) organized by ATINER throughout the year and entail significant costs of participating. The intellectual property rights of the submitting papers remain with the author. Before you submit, please make sure your paper meets the basic academic standards, which includes proper English. Some articles will be selected from the numerous papers that have been presented at the various annual international academic conferences organized by the different divisions and units of the Athens Institute for Education and Research. The plethora of papers presented every year will enable the editorial board of each journal to select the best, and in so doing produce a top-quality academic journal. In addition to papers presented, ATINER will encourage the independent submission of papers to be evaluated for publication.

The current issue is the fourth of the seventh volume of the *Athens Journal of Sciences (AJS),* published by Natural & Formal Sciences Division of ATINER.

Gregory T. Papanikos, President, ATINER.

Athens Institute for Education and Research

A World Association of Academics and Researchers

9th Annual International Conference on Chemistry
19-22 July 2021, Athens, Greece

The Chemistry Unit of ATINER, will hold its **9th Annual International Conference on Chemistry, 19-22 July 2021, Athens, Greece** sponsored by the Athens Journal of Sciences. The aim of the conference is to bring together academics and researchers of all areas of chemistry and other related disciplines. You may participate as stream organizer, presenter of one paper, chair a session or observer. Please submit a proposal using the form available (https://www.atiner.gr/2021/FORM-CHE.doc).

Academic Members Responsible for the Conference

- **Dr. Ellene Tratras Contis**, Head, Chemistry Unit, ATINER & Professor of Chemistry, Eastern Michigan University, USA.
- **Dr. Nicolas Abatzoglou**, Head, Environment Unit, ATINER & Professor, Department of Chemical & Biotechnological Engineering, University of Sherbrook, Canada, Chair Pfizer, PAT in Pharmaceutical Engineering, Director GREEN-TPV and GRTP-C & Pwelcomes.

Important Dates

- Abstract Submission: **21 December 2020**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **21 June 2021**

Social and Educational Program

The Social Program Emphasizes the Educational Aspect of the Academic Meetings of Atiner.

- Greek Night Entertainment (This is the official dinner of the conference)
- Athens Sightseeing: Old and New-An Educational Urban Walk
- Social Dinner
- Mycenae Visit
- Exploration of the Aegean Islands
- Delphi Visit
- Ancient Corinth and Cape Sounion

Conference Fees

Conference fees vary from 400€ to 2000€
Details can be found at: https://www.atiner.gr/2019fees

Athens Institute for Education and Research

A World Association of Academics and Researchers

9th Annual International Conference on Physics
19-22 July 2021, Athens, Greece

The Physics Unit of ATINER, will hold its **9th Annual International Conference on Physics, 19-22 July 2021, Athens, Greece** sponsored by the Athens Journal of Sciences. The aim of the conference is to bring together academics and researchers of all areas of physics and other related disciplines. Please submit a proposal using the form available (https://www.atiner.gr/2021/FORM-PHY.doc).

Important Dates

- Abstract Submission: **21 December 2020**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **21 June 2021**

Academic Member Responsible for the Conference

- **Dr. Ethel Petrou**, Academic Member, ATINER & Professor and Chair, Department of Physics, Erie Community College-South, State University of New York, USA.
- **Dr. Bala Maheswaran**, Head, Electrical Engineering Unit, ATINER & Professor, Northeastern University, USA.

Social and Educational Program

The Social Program Emphasizes the Educational Aspect of the Academic Meetings of Atiner.

- Greek Night Entertainment (This is the official dinner of the conference)
- Athens Sightseeing: Old and New-An Educational Urban Walk
- Social Dinner
- Mycenae Visit
- Exploration of the Aegean Islands
- Delphi Visit
- Ancient Corinth and Cape Sounion

More information can be found here: https://www.atiner.gr/social-program

Conference Fees

Conference fees vary from 400€ to 2000€
Details can be found at: https://www.atiner.gr/2019fees

Athens Journal of Sciences- Volume 7, Issue 4, December 2020 – Pages 195-206

On the Vulnerability of the Egyptian Mediterranean Coast to the Sea Level Rise

By Tarek M. El-Geziry[*]

Sea level rise (SLR) along the Egyptian Mediterranean coast was valued using tide gauge data. There is considerable difference in both mean sea level and rate of increase in different parts of this stretched coastal zone. The tide gauge station at Sidi Abdel-Rahman showed a SLR of 1.0 mm/year. SLR at Alexandria Western Harbour and Mersa Matrouh was 2.2 and 2.4 mm/year, respectively. The SLR along the central Delta region was observed as 3.8 mm/year at Burullus. The stations in Port Said and Abu-Qir showed a SLR of 4.8 mm/year and 6.4 mm/yr, respectively. Moreover, physical vulnerability of the coast to changes in sea level was evaluated revealing that the Delta coastal zone is very high vulnerable to any SLR. In contrast, vulnerability along the western section of the Egyptian Mediterranean coast varies from moderate to high.

Keywords: *Egypt, Mediterranean, sea level, sea level rise, rates, vulnerability*

Introduction

Global sea level has risen at a rate of 1.8 mm/year over the 20th century as a consequence of the global temperature rise (IPCC 2007). This sea level rise (SLR) distresses coastal ecosystems (IPCC 2007, Nicholls et al. 2007) in numerous ways, *e.g.* coastal erosion, saltwater intrusion, flooding, etc. It will also affect the coastal communities and economies. As a low-elevated coast, the Egyptian Mediterranean coast is greatly vulnerable to SLR (El-Raey et al. 1999, Dasgupta et al. 2009, Syvitski et al. 2009, El-Deberky and Hunicke 2015). The projected SLR of 0.5 m in the 21st century may affect over 1800 km^2 of agricultural land and almost 3.8 million people in the Nile Delta from Alexandria to Port Said (Fitzgerald et al. 2008). All these factors reflecting the importance of monitoring the sea level variations along the Egyptian Mediterranean coast motivated this analysis of sea level, which includes a set of sea level data covering the Egyptian Mediterranean coast excluding its most eastern side off El-Arish and Rafah. Assessing vulnerability to SLR at different parts of the Egyptian Mediterranean coast is also examined in this study.

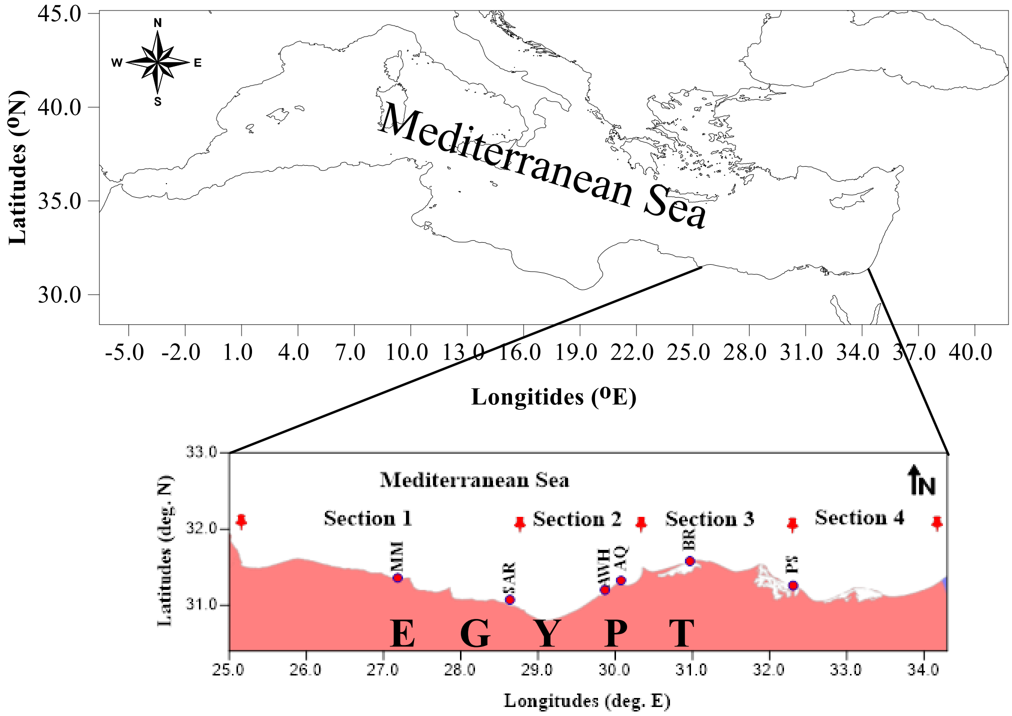
The Egyptian Mediterranean Coast

The Egyptian Mediterranean coast covers a length of about 1200 km from Rafah (31°17′19″N; 34°14′28″E) in the east to Sallum (31°30′13″N; 25°06′54″E) in the west (Figure 1). It comprises four different sections based on the physiographical characteristics. Therefore, coastal dynamical features are expected

[*]Associate Research Professor, Laboratory of Physical Oceanography, Division of Marine Environment, National Institute of Oceanography and Fisheries (NIOF), Egypt.

to differ from one section to another. The northwest Egyptian Mediterranean region (Section 1), extending from Sallum to Alamein, is featured by the highest elevation above the mean sea level (MSL) along the entire Egyptian Mediterranean coastline (Santamaria and Farouk 2011). Section 2, extending from Alamein to Alexandria, is the middle northern Egyptian Mediterranean region. This comprises Alexandria Western Harbour, which is the main Egyptian port on the Mediterranean. Then comes the Nile Delta section (Section 3), which stretches between Rosetta and Port Said. This is characterised by the largest population density in Egypt, and it is the main area where the agriculture activities exist. Lastly, the most eastern section (Section 4) is the north-eastern Egyptian Mediterranean region extending from Port Said to Rafah. It comprises the main zone of Egypt industrial and commercial activities, including the Suez Canal. Along this prolonged coast, five coastal lakes, namely: Mariut, Edku, Burullus, Manzalah and Bardawil, from west to east, respectively, are in connection with the Mediterranean Sea. In addition to this coastal lake system, the Egyptian Mediterranean coast is featured by the presence of ports and harbours of different activities, e.g., Alexandria and Port Said (Commercial and industrial harbours), El-Burullus (fishing harbour).

Figure 1. *The Mediterranean Basin with the Geographical Sections of the Egyptian Mediterranean Coast and Locations of Tide Gauges used in the Present Study*



Sea Level Rise along the Egyptian Mediterranean Coast

The sea level variation along the Egyptian Mediterranean coast is the result of the combined effects of astronomical tides and surge elevations. Tides are mainly semidiurnal, with a dominant tidal range in the order of a few centimetres (Hussein et al. 2010, Saad et al. 2011, El-Geziry and Radwan 2012, Said et al. 2012, Radwan and El-Geziry 2013). Surges, being affected by the meteorological conditions, may reach a height of 1.0 m (El-Geziry and Radwan 2012), and therefore, have more impact on the coast.

The coastal zone of the Egyptian Mediterranean Sea is exposed to numerous environmental stresses, which are mostly attributed to the anthropogenic activities associated with urban, industrial and agricultural development; producing pollutants of land-based sources (UNDP 2011). The SLR along the Mediterranean coast of Egypt is a major problem, and it has been recognised as highly vulnerable to climate change induced-SLR (UNDP 2014). Dasgupta et al. (2009) classified Egypt in the top ten most affected countries by SLR. The Nile and Niger Deltas were identified as the most threatened African deltas due to subsidence and human interference (Syvitski et al. 2009). Alexandria was ranked 11^{th} in terms of population exposed to coastal flooding in 2070s (El-Deberky and Hunicke 2015).

Several studies on the vulnerability of Alexandria indicated that a 0.3 m SLR would affect large parts of the city resulting in loss of billions of dollars infrastructure, displacement of over half a million inhabitants and in a loss of about 70,000 jobs (El-Raey et al. 1999). With a 1 m SLR, it is estimated that 68% (1,200 km^2) of Alexandria land could be inundated (Leatherman and Nicholls 1995). Alexandria is experiencing a SLR with a rate of 2.2 mm/yr (El-Geziry and Said 2020). Additionally, Alexandria is subsiding at a rate of 2 mm/yr and even without climate change, the city is highly vulnerable to flooding and erosion, as 35% (700 km^2) of the land area is below the mean sea level (El-Raey et al. 1995). Maiyza and El-Geziry (2012) showed that the land subsidence in the vicinity of Alexandria has the major impact on the observed sea level variations over the oceanographic and environmental factors. Chen et al. (1992) and Warne and Stanley (1993) calculated the land subsidence rate along Alexandria to vary between 0.5 and 7 mm/yr. Frihy (2003) examined the impacts of the SLR along the coast of the Nile Delta. He identified four main sections along the Nile Delta Coast as most vulnerable to SLR including; Burullus and Manzala lakes, western backshore zone of Abu Qir Bay, Manzala-Port Said area, and Ras El-Barr Beach. The study estimated that about 30% of the Nile Delta coast would be vulnerable to SLR. He also concluded that the land subsidence rate at Port Said and the Nile Delta is 5 mm/yr. According to Stanley (1997) the rate of the Nile Delta subsidence is relatively lower than that of the other river deltas in the Mediterranean Basin: Rhone, Po and Ebro, which can examine a subsidence up to 10 mm/yr. The Nile Delta is not only affected by SLR but also by the problem of land subsidence. The risk assessment of exposure in Kafr El-Sheikh Governorate in the Nile Delta region, based on the B1 and A1FI scenarios of the IPCC (2007) revealed that no noteworthy altration was detected between the 2 scenarios with respect to the SLR impacts (Hassaan 2013). Among the ten districts of the Governorate, more than 40% of the total area of five districts is expected to be lost due to inundation by SLR. Port Said is Egypt's second largest harbour examines a SLR rate of 4.8 mm/yr (El-Geziry and Said 2020). It is also suffering from a land subsiding at 5 mm/yr, and therefore, the SLR there would become more severe than other parts of the Egyptian Mediterranean coast (El-Raey 1997). In case of a 0.5 m SLR, a loss of 1.6% (21 km^2) beach area, 8% (0.46 km^2) urban area, and 13% (0.05 km^2) industrial area, in addition to other physical and socio-economic damages would be expected in Port Said Governorate, costing a lot beyond US$2.2 billion (El-Raey et al. 1999, Agrawala et al. 2004).

Different approaches were proposed and investigated by Koraim et al. (2011); to protect the northern coast of Egypt from the SLR. This includes the soft construction techniques, the barriers, the coastal armoring, the elevated development, the floating development, the floodable development, managed retreat and the integrated coastal zone management approach.

Sea Level Rise in Coastal Vulnerability Index

Vulnerability is strongly correlated with the rate of the SLR. Rates of relative sea level variations are significant inputs in the calculations of a coastal vulnerability index. This index is one of the prognostic methods to coastal classification by combining several variables from natural and human environments from a variety of sources (McLaughlin and Cooper 2010). Moreover, a coastal vulnerability index helps to evaluate and classify responses to progressive changes and modifications in the dynamic of any coastal zone (Hamid et al. 2019). All studies consider that a lower SLR rate or a fall in the sea level (negative values) represents the least vulnerable coast (Gornitz 1991, Gornitz and White 1991), as shown in Table 1. Moreover, small intervals are used on coasts where the range of the sea level change is small (Abuodha and Woodroffe 2010), and higher intervals are used where a high range of sea level exists (Ozyurt and Ergin 2010).

Table 1. *Vulnerability of Coastal Zone on the Basis of Relative SLR Rates*

Reference	Very low	Low	Moderate	High	Very high
Gornitz (1991)	≤ -1.1	-1.0–0.99	1.0–2.0	2.1–4.0	≥ 4.1
Gornitz and White (1991)	≤ -1.1	-1.0–0.99	1.0–2.0	2.1–5.0	≥ 5.1
Abuodha and Woodroffe (2010)	< 0.0	0.0–0.9	1.0–2.0	2.1–3.0	> 3.1
Ozyurt and Ergin (2010)	< 1.0	1.0–2.0	2.0–5.0	5.0–7.0	> 7.0

Data and Methods of Analysis

The present work is using hourly sea level records from six tide gauges installed along the Egyptian Mediterranean coast (Figure 1), at Mersa Matrouh (MM), Sidi Abdel-Rahman (SAR), Alexandria Western Harbour (AWH), Abu-Qir Bay (AQ), Burullus new harbour (BR) and Port Said (PS) from west to east, respectively. The period of data differs from one location to another (Table 2). The recorded sea level at each location is referred to the zero level of the instrument.

The MSL is frequently defined as the average value of hourly sea levels recorded over a period of at least one year period, and preferably over about 19 years; to average over the 18.61 years cycle in the tidal amplitudes and phases, and to average out weather (Pugh and Woodworth 2014). Therefore, the MSL in the present work is calculated as the arithmetic average of the hourly sea levels from each tide gauge at every location. The MSL is referred inhere to the tide gauge zero level.

Table 2. *Locations, Positions and Periods of Sea Level Records in the Present Study*

Tide Gauge Location	Tide Gauge Position		Period of REcords	% of missed data
	Lat. (deg. N)	Long. (deg. E)		
Mersa Matrouh (MM)	31.256	32.305	4 years (2003–2006)	0
Sidi Abdel-Rahman (SAR)	31.582	30.968	5 years (2012–2016)	0
Alex. Western Harbour (AWH)	31.325	30.075	33 years (1974–2006)	9.1
Abu-Qir Bay (AQ)	31.199	29.866	21 years (1990–2010)	0
Burullus (BR)	31.07	28.636	6 years (2003–2008)	0
Port Said (PS)	31.36	27.183	8 years (2003–2010)	0

Results

Sea Level Changes

Based on the available hourly data the MSL at the six locations is calculated to be 32, 35, 48, 48, 62 and 67 cm at MM, SAR, AWH, AQ, BR and PS, respectively. This reveals a general behaviour of declination in the sea surface from east to west, with a difference of 35 cm between the two sides. Moreover, the sea level range (difference between high and low water levels) is 17, 4, 20, 10, 20 and 40 cm at MM, SAR, AWH, AQ, BR and PS, respectively.

Changes in the rates of SLR along the Egyptian Mediterranean coast indicate significant variation between the calculated rates in the different parts of this coastline. These rates were recently calculated by El-Geziry and Said (2020) to be 1.0 mm/year at SAR, 2.2 and 2.4 mm/year at AWH and MM, respectively, 3.8 mm/year at BR, and 4.8 and 6.4 mm/year at PS and AQ, respectively. Generally speaking, the sea level change along the western part of the Egyptian Mediterranean coast shows low rise rates in contrast to its eastern part. The overall rate of the SLR along the Egyptian Mediterranean coast is 3.4 mm/yr (El-Geziry and Said 2020).

Vulnerability of the Egyptian Mediterranean Coast to Sea Level Rise

The relative vulnerability of different coastal environments to the SLR may be measured on a regional to national scale using elementary information on coastal geomorphology, SLR rate, past shoreline evolution, mean tidal range, and mean wave height (Thieler and Hammar-Klose 1999, Ozyurt and Ergin 2010). A considerable variation has been observed in the calculated rates of mean annual sea level rise along the Egyptian Mediterranean coast. As the sea level ranges are generally low along the Egyptian Mediterranean coast, the vulnerability index by Abuodha and Woodroffe (2010) will be applied in this study.

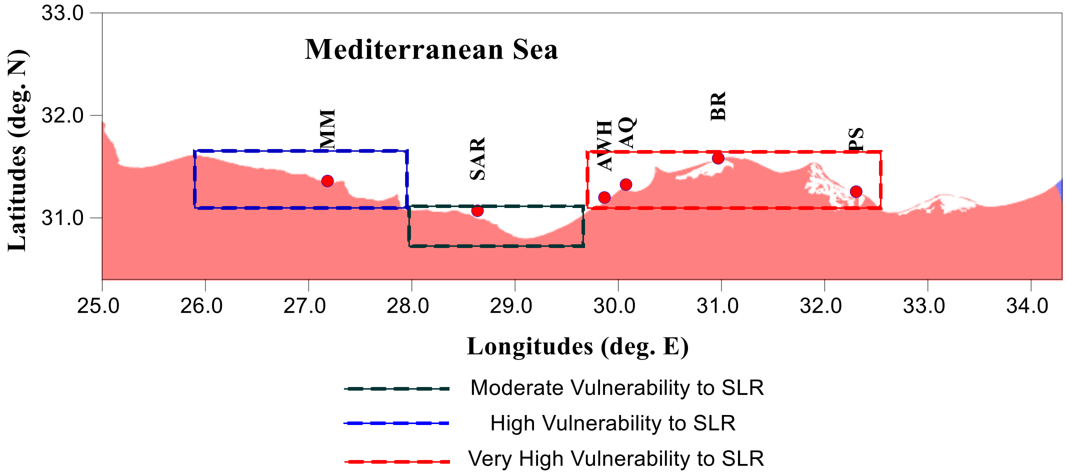
With respect to the calculated SLR rates, vulnerability of the Egyptian Mediterranean coast to sea level rise variates from high to very high, except the region of SAR, which can be classified as moderately vulnerable. Taking the land subsidence rate into consideration, the calculated rates become higher: The northwest section of the Nile Delta comprising AWH and AQ is believed to be subsiding by 3.7 mm/year, while the central section comprising BR has a subsidence rate of 7.7 mm/yr (Stanley and Clemente 2017). Thus, the relative SLR of these three coastal zones becomes 5.9, 10.1 and 11.5 mm/year, respectively.

The northeast sector of the Nile Delta coast comprising PS demonstrated a high rate of SLR. The calculation revealed a rate of 4.8 mm/year (El-Geziry and Said, 2020). After incorporating local land level subsidence, which is estimated to be 8.4 mm/yr (Stanely and Clemente 2017), the relative rise exceeds 13 mm/year.

Because of these high rates of relative SLR, the coastal zone from Alexandria to Port Said has been considered as a very high vulnerable coast (Figure 2).

On the other hand, the western sector of the Egyptian Mediterranean Coast comprising SAR and MM has examined a low rate of SLR of 1.0 mm/yr and 2.4 mm/yr, respectively (El-Geziry and Said 2020). Unfortunately, no information is available at present on land subsidence and its rate in this sector. Therefore, the extent of the SLR in this western coastal zone can be treated as moderate to high vulnerable (Figure 2).

Figure 2. *Vulnerability of the Egyptian Mediterranean Coast to Sea Level Change*



From a tidal range point of view, the Egyptian Mediterranean coast can be categorised as having microtidal range. The region that has a microtidal range characteristic is determined as a very high vulnerable to SLR (Abuodha and Woodroffe 2010, Ozyurt and Ergin 2010). This is mainly attributed to the potential influence and greatest risk of storm impact on the coastline versus to the tidal range effect.

Discussion

Being classified as low-elevated coastal zone, the Egyptian Mediterranean coast has got special attention because of potential hazards from the sea level rise (SLR).

Data availability and quality are great concerns in assessing rates and behavior of the SLR. Tide-gauge data from six tide-gauges distributed along the Egyptian Mediterranean coast were used to calculate the MSL and ranges in the present work. The rates of the SLR were recently calculated by El-Geziry and Said (2020) using the same data sets. The deployment locations represent the four different sections of the Egyptian Mediterranean coast.

Results revealed significant variations in the calculated MSL along the Egyptian Mediterranean coast, with a general slope of declination from east (PS) to west (MM). This is in consistent with the atmospheric pressure system of Lows and Highs impacting on the Levantine Basin (Tsimplis et al. 2005, Gomis et al. 2008, Oddo et al. 2014). The present results on the tidal ranges assure the microtidal pattern of the Egyptian Mediterranean coast. This is in agreement with the classification of Manohar (1981) and Hereher (2015). Rates of SLR along the different parts of the coast are varying and changeable at the local scale but meanwhile point out a general pattern of increase over the whole coast. The overall average rate of SLR along the Egyptian Mediterranean coast is calculated to be about 3.4 mm/yr (El-Geziry and Said 2020), which is larger than the global SLR rate for the 20th century of 1.8±0.5 mm/yr (Church and White 2011) and for the whole Mediterranean basin rates of 1.1-1.3 mm/yr (Tsimplis and Baker 2000). However, this rate is less than that calculated for the Eastern Mediterranean of 04-20 mm/yr (Tsimplis et al. 2008, Vigo et al. 2011, Passaro and Seitz 2012). It worth declaring the mid-to-east sector of the Egyptian Mediterranean coast comprising AQ, BR and PS is affected by higher SLR rates than its mid-to-west sector (AWH, SAR and MM). This may be a direct result of the pronounced land subsidence taking place in this eastern region of the Egyptian Mediterranean coast. The SLR at SAR, AWH and MM stations have shown rates of 1.0, 2.2 and 2.4 mm/year, respectively. The SLR obtained at AQ was the highest, being 6.4 mm/yr. At BR and PS, the SLR rate was 3.8 and 4.8 mm/yr, respectively. These rates are in agreement with those previously calculated over different periods and at different locations along the Egyptian Mediterranean coast (e.g., El-Fishawi and Fanos 1989, Frihy 1992, 2003, Shaker et al. 2011, Said et al. 2012, Maiyza and El-Geziry 2012).

Vulnerability is tightly related to the number of people affected by a hazard and their adaptive capacity. Hence the use of the term "vulnerability" in the present work, which mainly assessed physical vulnerability of the coastal zone toward the SLR, might undermined its true meaning in the disaster reviews or development terminology. Abuodha and Woodroffe (2010) have chosen to use the term "sensitivity" instead, to explain the susceptibility of a coast. The assessment of vulnerability could be practiced by integrated sensitivity with affected environment, population and their adaptive response variables. The sea level rise imposes the greatest threat to the Egyptian Mediterranean coast along its central part comprising the Nile Delta with its two extremities including cities of Alexandria and Port Said. The Delta coast is composed of flat deltaic sediments for a distance of about 250 km as a consequence of the long-lasting Nile River flooding (Hereher 2015). According to the present analysis, this part of the Egyptian coastal zone densely populated and where lands are very fertile is classified as very high vulnerable zone to sea level rise. This comes in agreement with the conclusions of El-Hattab (2015) and Hereher (2015). Generally speaking, the geomorphology of the coast between Sidi Abdel Rahman and Mersa Matrou to Sallum (~250 km) is a rocky calcareous rocks beach with a natural vertical cliffs sloping (Frihy 2009). The area between Alexandria and Alamein (~100 km) is generally low cliffy coast (Hereher 2015). The present results revealed that the coastal zone of the most far western coastal region of Mersa Matruh is high vulnerable and that around Sidi Abdel Rahman zone is moderately vulnerable to the SLR. This contradicts with Hereher's conclusion that this area has a low to a very low vulnerability. This contradiction may be attributed to the consideration of only one parameter in the present work, *i.e.* sea level, to highlight areas susceptible and vulnerable to the sea level rise problem along the Egyptian Mediterranean Coast.

Conclusions

In conclusion, the calculated SLR rates along the Egyptian Mediterranean Coast are within the known categories of both global and Mediterranean rates. The sea level ranges are also in agreement with the known ranges of this coastal zone. The varying vulnerability classification to SLR along the Egyptian coast is mainly attributed to the different composition of strata over this coast and to the different behaviour and rates of land subsidence. Planning to overcome the impacts of sea level changes and land subsidence trends in the coastal zones requires management attention. These areas must be kept in top priority in dealing with this slow but highly destructive natural threat. A coastal vulnerability index can thus afford awareness concerning the virtual potential of coastal damage caused by sea-level rise and land subsidence. Despite the fragmented availability of data, this study provides a limited but prospective assessment of the Egyptian Mediterranean coast's vulnerability to future SLR. The created sea-level rise vulnerability map will assist coastal planners to handle the natural threat in more efficient way.

Acknowledgment

The author would like to thank Prof. Mohamed A. Said, Emeritus Professor of Physical Oceanography, National institute of Oceanography and Fisheries (NIOF), for providing the sea level data used to calculate the MSL and the sea level ranges in the present study.

References

Abuodha P, Woodroffe CD (2010) Assessing vulnerability to sea-level rise using a coastal sensitivity index: a case study from southeast Australia. *Journal of Coastal Conservation* 14(3): 189–205.

Agrawala S, Moehner A, El Raey M, Conway D, van Aalst M, Hagenstad M et al. (2004) *Development and climate change in Egypt: focus on coastal resources and the Nile*. Organisation for Economic Co-operation and Development (OECD).

Chen Z, Warne AG, Stanley DJ (1992) Late quaternary evolution of the northwest Nile delta between Rosetta and Alexandria, Egypt. *Journal of Coastal Research* 8(3): 527–561.

Church JA, White NJ (2011) Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32(4): 585–602.

Dasgupta S, Laplante B, Murray S, Wheeler D (2009) *Sea-level rise and storm surges: a comparative analysis of impacts in developing countries*. Policy Research Working Paper (WPS 4901). Washington, DC: World Bank Group.

El-Deberky Y, Hunicke B (2015). Vulnerability of the Nile delta to recent and future climate change. In *Proceedings of the 36th IAHR World Congress*, The Netherlands, 28 June–3 July, 2015.

El-Fishawi NM, Fanos AM (1989) Prediction of sea-level rise by 2100, Nile delta coast. *INQUA, Commission on Quaternary Shorelines Newsletter* 11: 43–47.

El-Geziry T, Radwan A (2012) Sea level analysis off Alexandria, Egypt. *Egyptian Journal of Aquatic Research* 38(1): 1–5.

El-Geziry TM, Said MA (2020) Spatial variations of sea level along the Egyptian Mediterranean coast. *Athens Journal of Mediterranean Studies* 6(2): 141–154.

El-Hattab MM (2015) Improving coastal vulnerability index of the Nile delta coastal zone, Egypt. *Journal of Earth Science and Climatic Change* 6(8): 293–299.

El-Raey M (1997) Vulnerability assessment of the coastal zone of the Nile delta, Egypt, to the impacts of sea level rise. *Ocean and Coastal Management* 37(1): 29–40.

El-Raey M, Nasr S, Frihy O, Desouki S, Dewidar K (1995) Potential impacts of accelerated sea-level rise on Alexandria Governorate, Egypt. *Journal of Coastal Research* 14: 190–204.

El-Raey M, Frihy O, Nasr S, Desouki S, Dewidar K (1999) Vulnerability assessment of sea level rise over Port Said Governorate, Egypt. *Environmental Monitoring and Assessment* 5(2): 113–128.

Fitzgerald DM, Fenster MS, Argow BA, Buynevich IV (2008) Coastal impacts due to sea-level rise. *Annual Review of Earth and Planetary Sciences* 36(1): 601–647.

Frihy OE (1992) Sea-level rise and shoreline retreat of the Nile delta promontories, Egypt. *Natural Hazards* 5(Jan): 65–81.

Frihy OE (2003) The Nile delta-Alexandria coast: vulnerability to sea-level rise, consequences and adaptation. *Mitigation and Adaptation Strategies for Global Change* 8(2): 115–138.

Frihy OE (2009) Morphodynamic implications for shoreline management of the western-Mediterranean sector of Egypt. *Environmental Geology* 58(6): 1177–1189.

Gomis D, Ruiz S, Sotillo MG, Álvarez-Fanjul E, Terradas J (2008) Low frequency Mediterranean Sea level variability: the contribution of atmospheric pressure and wind. *Global and Planetary Change* 63(2–3): 215–229.

Gornitz V (1991) Global coastal hazards from future sea level rise. *Palaeogeography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section)* 89(4): 379–398.

Gornitz V, White TW (1991) The global coastal hazards data base. In *Future Climate Studies and Radio-Active Waste Disposal, Safety Studies*, 214–224. England.

Hamid AIA, Din AHM, Yusof N, Abdullah NM et al. (2019) Coastal vulnerability index development: a review. In *6th International Conference on Geomatics and Geospatial Technology (GGT 2019), Kuala Lumpur, Malaysia*.

Hassaan MA (2013) GIS-based risk assessment for the Nile delta coastal zone under different sea level rise scenarios case study: Kafr EL Sheikh Governorate, Egypt. *Journal of Coastal Conservation* 17(4): 743–754.

Hereher ME (2015) Coastal vulnerability assessment for Egypt's Mediterranean coast. *Geomatics, Natural Hazards and Risk* 6(4): 342–355.

Hussein M, Moursy Z, Tayel M (2010) General pattern of Alexandria western harbor sea level change. *Journal King Abdul-Aziz University (JKAU), Marine Science* 21(2): 47–61.

Intergovernmental Panel on Climate Change - IPCC (2007) *Climate change 2007: the physical science basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S Solomon, D Qin, M Manning, Z Chen, M Marquis, KB Averyt et al. (eds). Cambridge, UK and New York, USA: Cambridge University Press.

Koraim AS, Heikal EM, Abo Zaid AA (2011) Different methods used for protecting coasts from sea level rise caused by climate change. *Current Development in Oceanography* 3(1): 33–66.

Leatherman SP, Nicholls RJ (1995) Accelerated sea-level rise and developing countries: an Overview. *Journal of Coastal Research* 14: 1–14.

Maiyza IA, El-Geziry TM (2012) Long term sea-level variation in the south-eastern Mediterranean Sea: a new approach of examination. *Journal of Operational Oceanography* 5(2): 53–59.

Manohar M (1981) Coastal processes at the Nile delta coast. *Shore Beach* 49: 8–15.

McLaughlin S, Cooper JA (2010). A multiscale coastal vulnerability index: a tool for coastal managers. *Environmental Hazards* 9(3): 233–248.

Nicholls RJ, Wong PP, Burkett VR, Codignotto JO, Hay J, Mclean R et al. (2007) Coastal systems and low-lying areas. In ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, CE Hanson (eds), 315–356. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. *Contribution of WG II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Oddo P, Bonaduce A, Pinardi N, Guarnieri A (2014) Sensitivity of the Mediterranean sea level to atmospheric pressure and free surface elevation numerical formulation in NEMO. *Geoscientific Model Development* 7(6): 3001–3015.

Ozyurt G, Ergin A (2010) Improving coastal vulnerability assessments to sea-level rise: a new indicator-based methodology for decision makers. *Journal of Coastal Research* 26(Mar): 265–273.

Passaro M, Seitz F (2012) Steric sea level variations in the central-eastern Mediterranean Sea from Argo observations. *Bollettino di Geofisica Teorica ed Applicata* 52(1): 131–147.

Pugh D, Woodworth Ph (2014) *Sea-level science understanding tides, surges, tsunamis and mean sea level*. Cambridge, UK: Cambridge University Press.

Radwan A, El-Geziry T (2013) Some statistical characteristics of surges at Alexandria, Egypt. *Journal King Abdul-Aziz University: Marine Sciences* 24(2): 31–38.

Saad NN, Moursy ZA, Sharaf El-Din SH (2011) Water heights and weather regimes at Alexandria Harbor. *International Journal of the Physical Sciences* 6(30): 7035–7043.

Said MA, Moursy ZA, Radwan AA (2012) Climatic change and sea level oscillations off Alexandria, Egypt. In *Proceedings of International Conference on Marine and Coastal Ecosystems*. Albania, 353–359.

Santamaria RM, Farouk M (2011) Study area characterisation. In Environmental Hydraulics Institute "IH Cantabria" (eds), 16–39. *Integrated Coastal Zone Management Plan for the Coastal Areas between Marsa Matruh and El-Sallum, Egypt*.

Shaker AA, Saad AA, Al-Naggar D, Faisal H (2011) Absolute sea-level rise estimation at Alexandria using tide records and GPS observations. In *FIG Working Week 2011, Bridging the Gap between Cultures, Marrakech, Morocco, 18–22 May 2011*.

Stanley DJ (1997) *Mediterranean deltas: subsidence as a major control of relative sea-level rise*. Monaco: Bulletin of Institute of Oceanography.

Stanley JD, Clemente PL (2017) Increased land subsidence and sea-level rise are submerging Egypt's Nile delta coastal margin. *GSA Today, Geological Society of America* 27(5): 4–11.

Syvitski JPM, Kettner AJ, Overeem I, Hutton EWH, Hannon MT, Brakenridge R et al. (2009) Sinking deltas due to human activities. *Nature Geoscience* 2(10): 681–686.

Thieler ER, Hammar-Klose ES (1999) *National assessment of coastal vulnerability to sea-level rise, US Atlantic coast* (Open-File Report no. 99-593, 1 sheet). Woods Hole (MA): United States Geological Survey.

Tsimplis MN, Baker TF (2000) Sea level drop in the Mediterranean Sea: an indicator of deep water salinity and temperature changes. *Geophysical Research Letters* 27(12): 1731–1734.

Tsimplis MN, Alvarez-Fanjul E, Gomis D, Fenoglio-Marc L, Perez B (2005) Mediterranean Sea level trends: atmospheric pressure and wind contribution. *Geophysical Research Letters* 32(20): L20602.

Tsimplis M, Marcos M, Somot S (2008) 21st century Mediterranean sea level rise: steric and atmospheric pressure contributions from a regional model. *Global and Planetary Change* 63(2–3): 105–111.

United Nations Development Program - UNDP (2011) *Egypt's national strategy for adaptation to climate change and disaster risk reduction*. United Nations Development Program.

United Nations Development Program - UNDP (2014) *Adaptation to climate change in the Nile delta through integrated coastal zone management*. United Nations Development Program.

Vigo MI, Sánchez-Realesa JM, Trottini M, Chaoc BF (2011) Mediterranean Sea level variations: analysis of the satellite altimetric data, 1992–2008. *Journal of Geodynamics* 52(3–4): 271–278.

Warne AG, Stanley DG (1993). Late Quaternary evolution of the northwest Nile delta and adjacent coast in the Alexandria region, Egypt. *Journal of Coastal Research* 9(1): 26–64.

Athens Journal of Sciences- Volume 7, Issue 4, December 2020 – Pages 207-224

Experimental Studies on the Characterization of Niger Delta Smectite and its Performance as a Geochemical, Bacteriological, and Geotechnical Barrier System

By Davidson E. Egirani[*], Nabila Shehata[±], Ifeoma Mary Ugwu[‡] & Alfred Opukumo[+]

This paper investigated the geochemical, bacteriological, and geotechnical characteristics of a smectite clay sourced in the Niger Delta Region of Nigeria and its application as a barrier system for the containment of pollutants in aqueous systems. The smectite clay was tested for various geochemical, bacteriological, and geotechnical properties. The findings revealed that the clay type had the potential to act as a barrier system for toxic heavy metals and bacteria in aqueous systems. The hydraulic conductivity of the smectite clay under effective stress of 80 kN/m^2 was 1.6 x 10^{-10} m/s to natural aqueous contaminants contained in the Gbarain watershed of the Niger Delta region of Nigeria. The Gbarain watershed contained Lead (>0.01 mg/L), Mercury (>0.006 mg/L), Manganese (>0.4 mg/L) and Escherichia coli (>0 cfu/100ml). Uptake of the inorganic contaminants and inhibition of bacteria by the smectite clay was significant and increased with an increase in pH. In conclusion, smectite clay would provide an excellent geochemical, bacteriological, and geotechnical barrier system for toxic heavy metals and bacteria migration into a watercourse.

Keywords: *Characterization, smectite, performance, Niger Delta region, barrier systems*

Introduction

The generation of inorganic and organic wastes in the aqueous environment is as old as the beginning of the human settlement. Metal load above the international recommended level has been observed in the Gbarain watershed of the Niger Delta region of Nigeria. The water quality, especially, groundwater in this region was contaminated with excessive metal load and bacterial infection. A 3-barrier system has been suggested to enhance the water quality using locally sourced clay in the same region.

In this study, a locally sourced smectite clay in the Niger Delta region of Nigeria (i.e., Amelem) was characterized in a laboratory using geochemical, bacteriological, and geotechnical techniques. This smectite clay used to treat aqueous toxic heavy metals and bacteria migrating into a watershed clay. Some

[*]Lecturer/Consultant, Faculty of Science, Niger Delta University, Nigeria.
[±]Lecturer, Faculty of Postgraduate Studies for Advanced Science (PSAS), Beni-Suef University, Egypt.
[‡]Lecturer, Faculty of Science, Enugu State University, Nigeria.
[+]Lecturer, Faculty of Science, Niger Delta University, Nigeria.

objectives of the study include determination of adsorption efficiency of the smectite clay at different pH, determination of the clay permeability under various effective stresses, and determination of E. coli content in samples of water obtained in the Gbarain watershed. This study, therefore, forms a critical step in a series of steps required in the containment of contaminants affecting aqueous systems.

Within the context of this paper, inorganic and organic wastes from the smelting of metals and food waste from food vendors respectively, constitute an environmental liability (Agbozu et al. 2015, Tansel and Yildiz 2011, Fuller 2018). Toxic heavy metal contaminants generated by reckless disposal of inorganic wastes has, therefore, compromised the water quality in most parts of the world. Metal and bacteriological loads besides, in the Gbarain watershed in the Niger Delta Region of Nigeria, are above recommended international limits set by the World Health Organization-(WHO). The WHO limits the contaminate values of Lead, Mercury, Manganese, and Escherichia coli in drinking water as <0.01 mg/L, <0.006 mg/L, <0.4 mg/L, and 0 cfu per 100 mL of Escherichia coli, respectively (Misstear et al. 2017). Both organic and inorganic wastes dumped along the flanks of streams within the Gbarain watershed. Subsequently, metal and bacteriological pollutants exist and interact with the Gbarain watershed (Oluwapelumi 2015).

This excessive mixed load is, therefore, a problem and reduction of this load to acceptable limits has generated considerable interest to researchers. Previous methods used in waste management in the Gbarain watershed include burning, recycling, reduce, reuse, incineration, and composting (Tansel and Yildiz 2011). These procedures are not capable of reducing metal and bacteriological load to acceptable level in watercourses in the watershed. A by-product of these methods may in, addition, washed into the soil by rain, thus contaminating the surface and groundwater resources (Velenturf and Jopson 2019). All procedures mentioned previously are not capable of disinfecting water contaminated with E. coli and coliform. During disinfection, pathogenic microorganisms in the water deactivated. Disinfection of the water is by chemical and physical means (Unuabonah et al. 2018). Chemical agents such as chlorine and its compounds used in the treatment of water in this region because of their effectiveness, and low cost The introduction of these chemicals to water, however, reacts with natural water to produce disinfection by-products (DBPs), that may be carcinogenic (Unuabonah et al. 2018). Using techniques not involving the addition of chemicals, such as filtration and adsorption by clay minerals has been of great interest to the international community. Some methods and combination of methods used for treating water contaminated with inorganic pollutants include ion exchange, membrane filtration, and coagulation-flocculation-sedimentation (Fu and Wang 2011). In adsorption of inorganic pollutants, the use of clay minerals has been a subject of interest to researchers (Zaki et al. 2017, Egirani et al. 2019).

Clay minerals are readily available used in the elimination of toxic heavy metals from water (Izah et al. 2018). Clay minerals are known to do effective adsorption of pollutants and barrier their migration. This ability of clay is dependent on the structure and chemical compositions (Cantor et al. 2010). The clay mineral of the smectite group includes bentonite and is composed mainly of hydrous magnesium-calcium aluminium silicate called montmorillonite. Clay minerals possess high colloidal and plastic properties with fine particles (Murray 1999).

For effective containment of an aquatic system, adsorption of metal and bacteriological load entering it is necessary. For effective elimination of these loads, however, a combination of adsorption and establishment of barrier systems are required (Xue et al. 2012). A suitable clay barrier system provides for clean, potable water, and sustainable water resource management. A clay barrier system, therefore, provides a protective structural barrier and adsorbing geochemical medium to control the movement of contaminants (Zaki et al. 2017). The performance of a clay barrier system is measured in terms of hydraulic conductivity, and chemical properties of the clay mineral. The functionality of a clay barrier system is dependent on the type of contaminants, the geotechnical, and chemical properties of the clay barrier (Ghazizadeh and Bareither, 2018). The critical function of a barrier system is to hold back the contaminants in a manner that is protective of human health and the environment. In meeting these requirements, a clay barrier system must possess low hydraulic conductivity and high adsorption capacity (Ghazizadeh and Bareither 2018). Over time, a clay barrier system with a field hydraulic conductivity of $1x10^{-9}$ m/s or less as reported by Oluwapelumi (2015) satisfies the requirements. A clay-based barrier system must be able to attenuate the movement of contaminants and retard the discharge of the pollutants into watercourses. Hydraulic conductivity is controlled primarily by the structural content of the clay (Oyediran and Olalusi 2017). Various researchers have supported the view that the percentages for fines for barrier clay is from 40% and 50%, and plasticity indices is from 10% and 30%. For some studies involving organic contaminants, the hydraulic conductivity increased when the concentration of chemical solutions increased (Hakan et al. 2018). The decrease in the hydraulic conductivity as a contaminant introduced into the barrier system has, however, reported. This characteristic may be related to the effects of the fluid composition on the clay structure i.e. the distribution of electric charges on the surface of the clay minerals (Sipos et al. 2018).

Consistency limits (Atterberg limits) are useful indicators of clay behaviour (Liu et al. 2018a). Diverse views exist on the effect of chemicals on the consistency limits of clays (Sipos et al. 2018). Liquid limit and plastic limit increased when the concentration of inorganic contaminants increased (Madsen and Mitchell 1989). The situation was different for organic pollutants where the increase in the concentration led to a decrease in the Atterberg limits. Organic chemicals tend to shrink a diffuse double layer that surrounds clay particles (Liu et al. 2018b). An effect of organic chemicals on the liquid limit behaviour of soil was studied by (Sipos et al. 2018). A metal load-contaminated sample, in this case, had lost its cohesive nature, possibly due to the collapse of the double layer in the presence of organic chemicals. As the liquid limit and plastic limit values were correspondingly increased or decreased, there is no overall change in plasticity index values as the contaminated water introduced into the system.

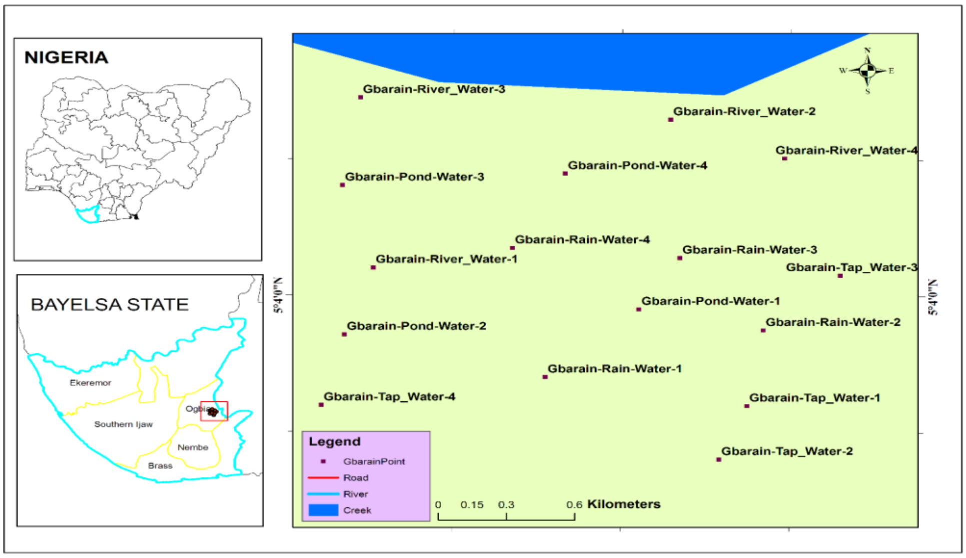
The influence of pH on the adsorption of metal ions on Na-montmorillonite was studied (Abollino et al. 2003) and found that the adsorption of metals decreases with decreasing pH and vice versa. At low pH, the hydrogen ion competes with the metal-load towards the external sites. A silanol (Si–O-) and aluminol (Al–O-) groups are less deprotonated and are less available to retain metals. Adsorption of metals increases at moderate pH over the pH-adsorption edge. At high pH values, the metal ions showed high retention on clay mineral (Sipos et al. 2018). The clays of the smectite group montmorillonite have, therefore, used as a barrier system at waste disposal sites (Odom 1984, Missana et al. 2018).

Methodology

Experimental Site Location of the Gbarain Watershed

An area selected for this study is in a southern flank of the Niger Delta Region of Nigeria (60 2' 0" E-60 8' 0" E, and 40 42' 0" N-40 46' 0" N) as shown in Figure 1. This terrain is low-lying with elevations from below sea level in a southwestern flank of the region to about 40 m inland.

Figure 1. *Map Showing the Study Location and Sample Sites*



The Gbarain watershed presently hosts two waste-dump sites located along the flanks of a seasonal flow stream and seasonally waterlogged terrain. About 75% of the Niger Delta Region is associated with wetland, and annual rainfall is between 2000–3000 mm. Some parts of the Niger Delta flooded due to excessive rain, human manipulation of wet-land, and excessive release of water from Niger and Benue Rivers. An open aquifer in a watershed derived from a Benin formation that is sandy and richly drained in nature (Chukwuma and Uchenna 2018).

Experimental Methods

The smectite clay used for tests is commonly found in the Niger Delta region of Nigeria and obtained from Dangote Industries Limited, Lagos, Nigeria. This clay is locally known as Amelem and is named smectite clay in this study. Water samples collected in triplicates from a Gbarain watershed. The sampling included 25 samples of rainwater as a control, 25 samples of surface water, and 25 samples of groundwater. All three water types were analyzed for physical, chemical, and bacteriological characteristics. However, only the contaminated groundwater selected as a material for geochemical, bacteriological and geotechnical studies. This selection was because this study was aimed at ensuring the prevention of contaminants from contaminating the groundwater.

Pre-Treated Contaminated Water and Post-Treated Contaminated Water

Triplicates of water samples were taken at each sampling point and were later transported to the laboratory for chemical and bacteriological analyses. Only analytical grade reagent and chemicals obtained from Sigma Aldrich in Dorset, United Kingdom were used in preparing reagents and standards. A collection of surface water and groundwater samples were analyzed for pH, temperature, total dissolved solids (TDS) and electrical conductivity per standard methods Analytical methods were based on the American Public Health Association (Rice et al. 2012). The total hardness was determined by Titrimetric Method. The salinity was evaluated using Mohr's method (Rice et al. 2012). The biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) were determined using titrimetric analysis and colourimetric analysis respectively (Ngang and Agbazue 2016).

Determination of Adsorption Characteristics of the Niger Delta Clay

The chemical performance of the smectite clay was studied through batch adsorption tests. The batch adsorption test is a quick method that provides information about the metal affinity of smectite clay mineral, as well as the mechanism and kinetic reaction involved. For this test, contaminated water containing Fe, Pb, Hg and Mn with a concentration of 0.25 mg/L, 0.06 mg/L, 0.019 mg/L and 0.85 mg/L, respectively were used. These metals were selected since they were above the World Health Organization limits for potable water (Misstear et al. 2017). A set of batch adsorption tests was conducted by adding 2 g of smectite clay in 50 mL of contaminated water. Samples were taken after 24 hours on an incubator shaker at 100 rpm and ambient temperature. This time was adequate to reach equilibrium (Shafiq et al. 2018). After shaking, every mixture was centrifuged and filtered using a filter with a 0.45 μm pore size. The concentrations of Fe, Pb, Hg, and Mn before and after the adsorption tests were analyzed using the atomic absorption spectroscopy (AAS). Subsequently, the adsorption capacity was determined from the following linear equation (1):

$$Q_t = [C_0 - C_t]\frac{V}{m} \qquad (1)$$

Here, Co equals the initial metal concentration (mgL^{-1}) at time t=0, C_t equals the metal concentration (mgL^{-1}) at time t, V equals the volume of adsorbent suspension (L) and m is the weight of the adsorbent (g). Thermal regeneration of the spent smectite clay was carried out by treating it with 1M nitric acid, thus, resulting in 60% regain. The extracted clay was heated to 500°C for 24h (Shahadat and Isamil 2018).

Determination of Geotechnical Properties of the Niger Delta Clay

The particle size analysis was done using LS 13 320 Coulter Laser Diffraction particle size analyzer (Blott and Pye 2006). The hydraulic conductivity test was conducted on the smectite clay following the procedures described by Tong and Shackelford (2016) using a falling headwater constant tailwater system. Diameter and height of the clay sample were 60 mm and 40mm in the permeability test, respectively. A hydraulic conductivity test of the smectite clay using rainwater as control was also conducted. The index properties measured according to the D7263-09 and ASTM 2018.

Bacteriological Analysis of the Contaminated Water and Post Contaminated Treated Water

A quantitative bacteriological analysis was conducted to determine the total coliforms and Escherichia coli (Hachich et al. 2012). A total bacterial count was determined by the use of the standard plate counting (SPC) method. An Escherichia coli assay was evaluated by preparing and sterilizing them with ethanol. The plate was removed after 24 h and perfect circled colonies were identified as Escherichia coli (E. coli) and other colonies were counted as the total coliform. In details, water samples filtered and retained on a membrane filter were removed to the culture medium (mTEC for E. coli. in a Petri plate and incubated at ambient temperature (35°C) for 2 h. This process was followed-up by incubation at 44°C for 24 h for E. coli. The colonies that developed magenta colour on mTEC media were counted using the unaided eye as E. coli. Their counts were expressed in cfu/100 mL of the water ((Izah et al. 2018, Hachich et al. 2012).

Results

Characterization of the Niger Delta Clay

This clay has SiO_2 (54%), Al_2O_3 (17%), Fe_2O_3 (5.2%), CaO (1.5%), MgO (2.5%), Na_2O (0.40%), K_2O (1.5%), Moisture content (9.3 %), Loss on Ignition (15 %), CEC (56 mmol/g), specific surface area (414 m^2/g), and Point of Zero Salt Effect (7.13). An x-ray diffraction spectrum, scanning electron microscopy and energy dispersive spectroscopy also, indicated smectite as the key constituent and elemental constituents of smectite clay tainted with copper (Figures 2a and 2b). The smectite clay had a clay content of 80% and the particle size distribution curve is provided (Figure 3) (Murray 1999).

Pre-Treated Contaminated Water and Post-Treated Contaminated Water

Some results of physicochemical analysis of the rainwater, pretreated and post-treated contaminated water samples are presented (Table 1). In this study, the contaminated water samples contain toxic heavy metal load and bacteriological load above regional and international. The BOD and COD of the contaminated water were 7 mg O_2/L and 20 mg/L respectively.

Figure 2a. *X-Ray Diffraction Patterns of a Smectite Clay*

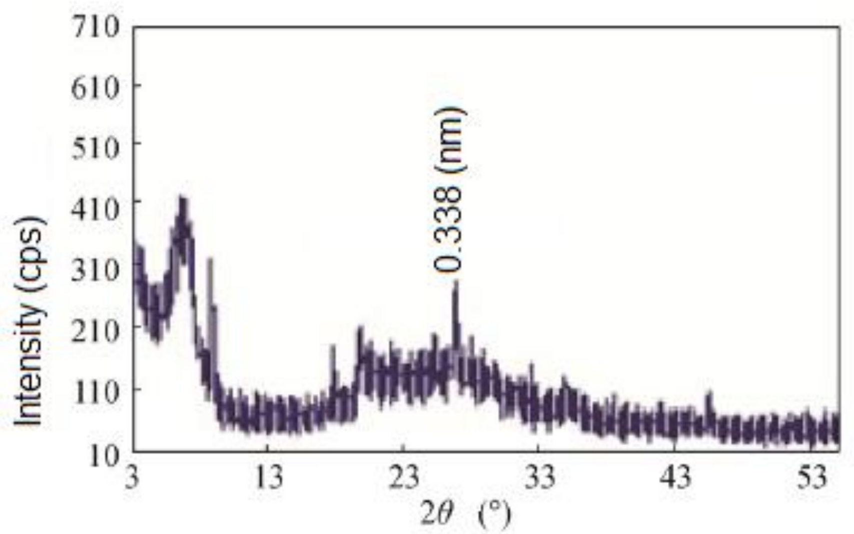


Figure 2b. *SEM and EDX of Smectite Clay*

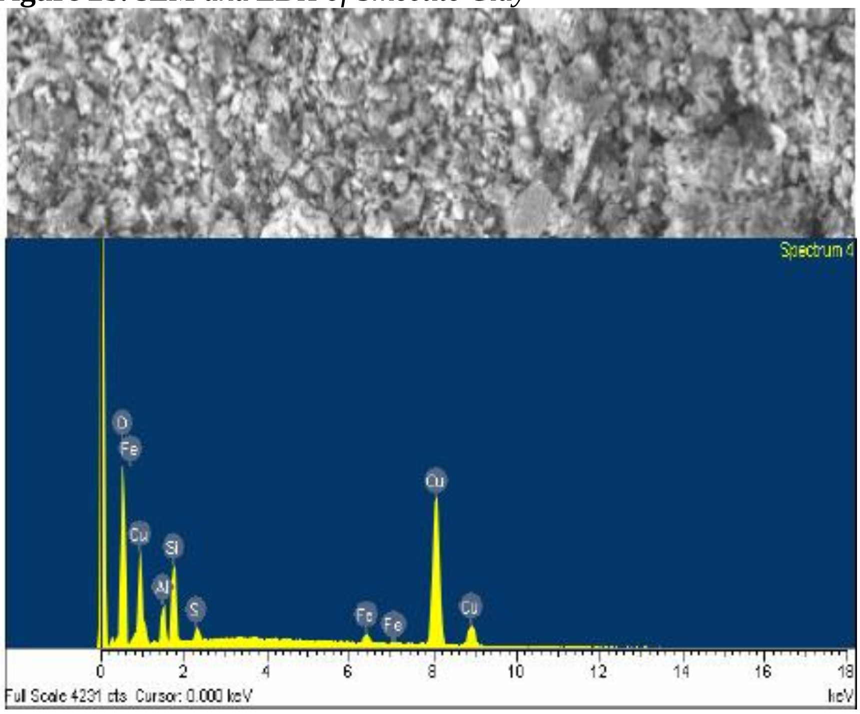
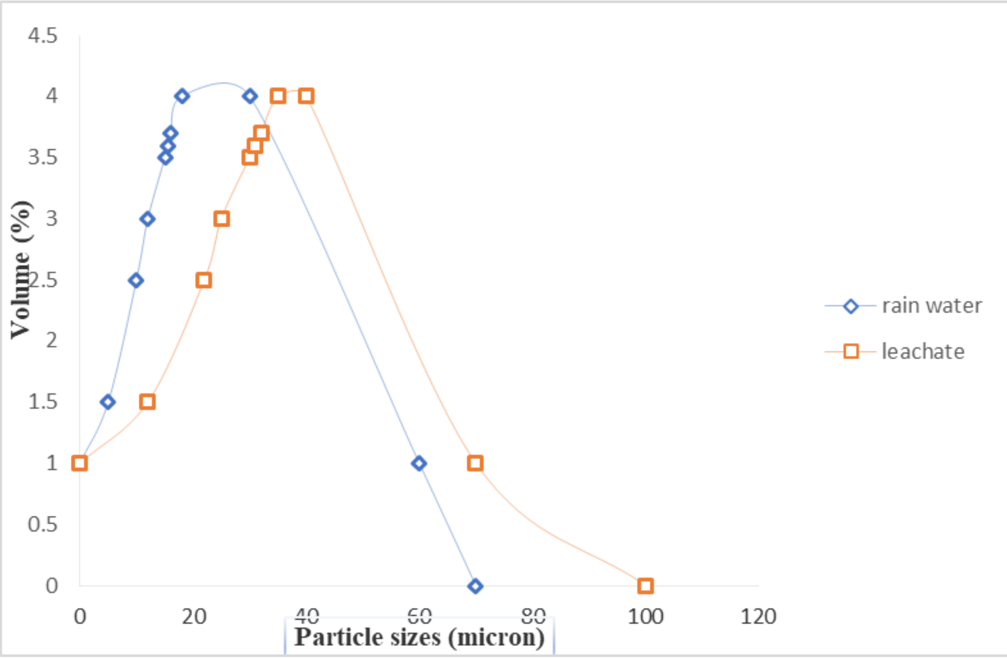


Figure 3. *Coulter Laser Particle Size Distribution Curve of Smectite Clay for Rainwater and Contaminated Water*



There was no statistically significant difference between groups (i.e., between particle sizes generated by rainwater and contaminated water or leachate as determined by one-way ANOVA (F(1,20)=1.540, p=0.229).

Table 1. *Some Index Properties of* Smectite Clay *Treated with Rainwater and Contaminated Water*

Smectite clay treated with	Liquid limit (%)	Plastic limit (%)	Particle size distribution		Plasticity index (%)	Optimum water content (%)
			Min diameter (μm)	Max diameter (μm)		
Rainwater	52	30	4	70	22	16
Contaminated water	35	18	6	100	17	12

There was a statistically significant difference between groups (i.e., between index properties generated by rainwater and contaminated water or leachate as determined by one-way ANOVA (F(1,10)=0.881, p=0.024). A short-term evaluation of the effluent at pH 6 indicated a reduction in groundwater contaminants. A decrease in the values of the metal load in an effluent is maybe because of the interaction of smectite clay with the contaminated water. For instance, the distribution of electric charges on a clay surface may account for interaction that led to the metal reduction.

Table 2. *Characterization of Water in the Study Location*

Water type	Temp ^0C	pH	EC µs/cm	Salinity µs/cm	Turbidity NTU	TDS ppm	Fe ppm	Pb ppm	Hg ppm	Mn ppm	Total alkalinity	E. coli 10^2 cfu/100 mL	T. coli 10^2 cfu/100 mL
Rain water	27.5	6.18	17.60	0.00	0.42	8.80	0.01	0.00	0.00	0.00	11.00	0	0
Surface water	28.7	6.23	56.70	1.34	17.50	28.40	0.30	0.06	0.04	0.80	11.00	3	5
Groundwater	26.8	6.32	168.0	0.8	2.15	83.00	0.25	0.05	0.01	0.50	14.00	1	2
Characterization of water treated with smectite at pH 6													
Rainwater	27.0	6.08	10.50	0.00	0.35	5.45	0.00	0.00	0.00	0.00	6.00	0	0
Groundwater	27.8	6.01	50.0	0.35	1.25	45.00	0.035	0.008	0.002	0.115	10.00	0	0

There was no statistically significant difference between groups was determined by one-way ANOVA ($F_{(4,15)}=2.055$, $p=0.138$). A Tukey post hoc test revealed that the metal concentration for treated water was statistically significantly lower after taking treated rainwater (4, p=0.000), and treated contaminated groundwater (4, p=0.04).

Bacteriological Analysis of Contaminated Water and Post-Treated Contaminated Water

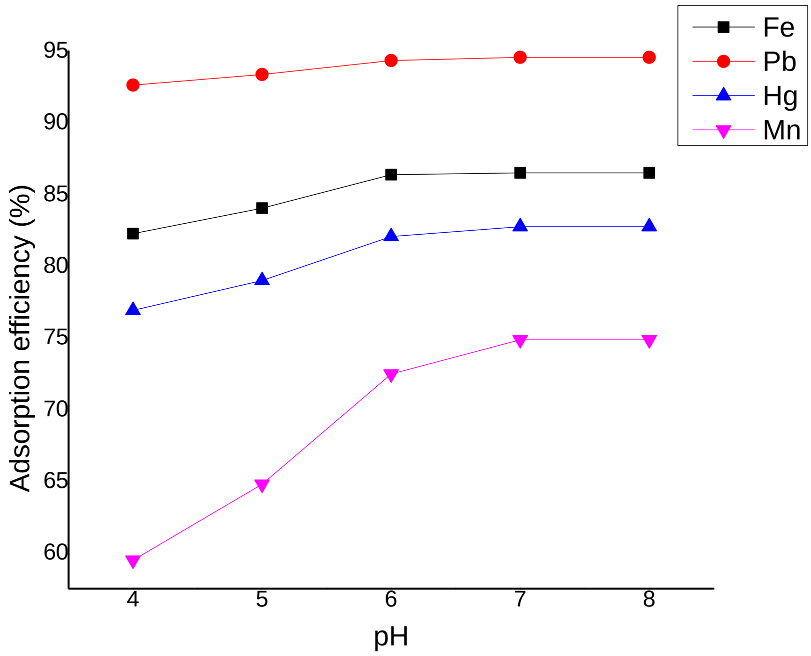
Some results for bacteriological analysis of rainwater, pre-treated contaminated water and post-treated contaminated water are presented (Table 2). Complete elimination of E. *coli* and Total coliform load were observed.

Discussion

Adsorption Performance of the Niger Delta Clay Interacted with Contaminated Water

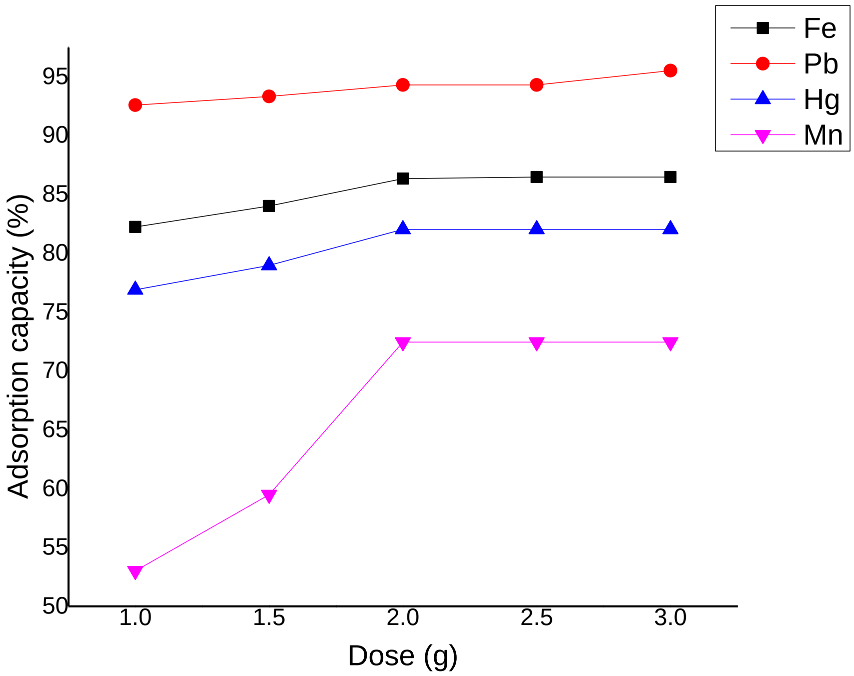
Some results for the adsorption test based on 2 g of smectite clay and THMs water at pH=6 is presented (Figures 4-5). Adsorption capacity of the smectite clay over the range of pH investigated (i.e., pH=4-8) revealed Fe (82-86%), Pb (92-94%), Hg (76-87%), Mn (59-74%).

Figure 4. *Plot of Adsorption Efficiency versus pH of Contaminated Water using 2 g of Smectite Clay*



There was a statistically significant difference in adsorption efficiency between groups of heavy metals as determined by one-way ANOVA (F (3,16) = 35.83, p = 0.00). A Tukey post hoc test revealed that the efficiency of adsorption was not statistically significantly different between subsets of heavy metals(p =1.000), (p=0.292), and (p=1.000).

Figure 5. *Plot of Adsorption Capacity versus Solid Concentration of Smectite Clay at pH 6*



There was a statistically significant difference in adsorption efficiency between groups of heavy metals as determined by one-way ANOVA (F(3,16)=29.052, p=0.00). A Tukey post hoc test revealed that the efficiency of adsorption was not statistically significantly different between subsets of heavy metals (p=1 .000), (p=0.442), and (p=1.000).

Uptake of inorganic pollutants by the smectite clay was found to be significant and increased with increased pH. At pH =6 and over the range of solid concentration investigated (i.e., 1-3 mg/L), the percentage of adsorption increased as solid concentration was increased. At pH=6 and 2.5 g/L, the percentage of adsorption was Fe (86.48 %), Pb (94.53%), Hg (82.72%), and Mn (74.84%).

The thermal regeneration of the spent smectite clay revealed a regain of 60% adsorption capacity. Thermal heating of the extracted smectite clay provided a 90% removal efficiency.

Some results indicated that the adsorption capacity of the smectite clay increased with increase in pH. These results conform to the chemical properties of smectite clay (Kloprogge et al. 1999).

The smectite clay adsorption mechanism was mainly based on their surface or ionic charge. The smectite clay was occupied by cations, and its surface was highly hydrophilic and pH-independent. The metals in contaminated water, therefore, interacted with the smectite clay and became adsorbed by ion exchange. The pH value of the reacting environment was one of some critical factors that determinized an interaction of the smectite clay with metal ions contained in the contaminated water (Scalia et al. 2018).

An increase in adsorption as pH was increased suggests that the ionic species of an inorganic contaminant was more readily adsorbed than the less ionic species. A significant role played by hydrophilicity was also observed from the pH effects. This phenomenon generally favoured adsorption because pH was high enough to ensure that a charged protonated species dominated a reaction process. Hydraulic conductivity of the smectite clay was governed by the chemical composition of the contaminated water and its pH. An increase in hydraulic conductivity of compacted natural clays occurred when a permeant liquid was an organic pollutant (Naka et al. 2012).

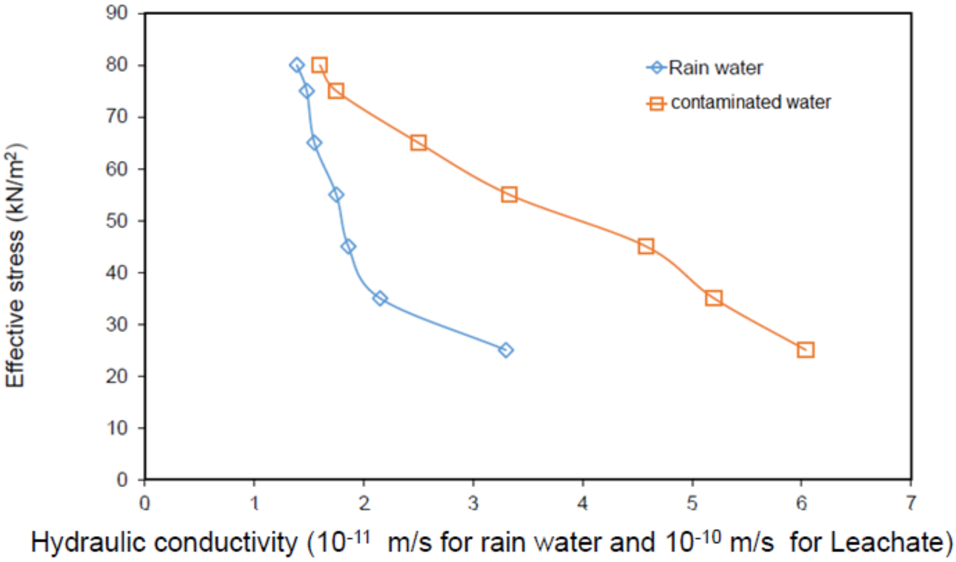
In this study using inorganic pollutants, a decrease in pH increased the hydraulic conductivity of the smectite clay increase in pH, therefore, decreased the hydraulic conductivity of the smectite clay. At low pH, the smectite clay possesses hydrophilic characteristics and hydrogen ion competes with metals contained contaminated-groundwater at reactive sites. Some silanol (Si–O-) and aluminol (Al–O-) groups also, became less deprotonated and less available (Naka et al. 2012, Delavernhe et al. 2018). At high pH values, the metal ions were highly adsorbed by the smectite clay.

Geotechnical Performance of the Niger Delta Clay Interacted with Contaminated Water

The smectite clay used in this study possesses hydraulic conductivity lower than $1x10^{-9}$ m/s and a high Cation Exchange Capacity and therefore, met the requirements for use as a barrier system. As the moisture content of the smectite clay changes from dry to wet of optimum, some fabrics of the smectite clay particles tended to change from a flocculated to a dispersed arrangement because of compaction. Higher effective stress produced closer alignment of particles along the failure surface thereby, yielding a decrease in the voids that conducted flow thus, lowering the hydraulic conductivity at higher effective stress (Oyediran and Olalusi 2017). This smectite clay demonstrated a capacity to attenuate the movement of contaminants and prolong the release of a metal load-bearing contaminated water.

Some results for short-term hydraulic conductivity evaluation are presented (Figure 6). This plot indicated that hydraulic conductivity of the smectite clay decreased when contaminated water was introduced into a clay mineral system.

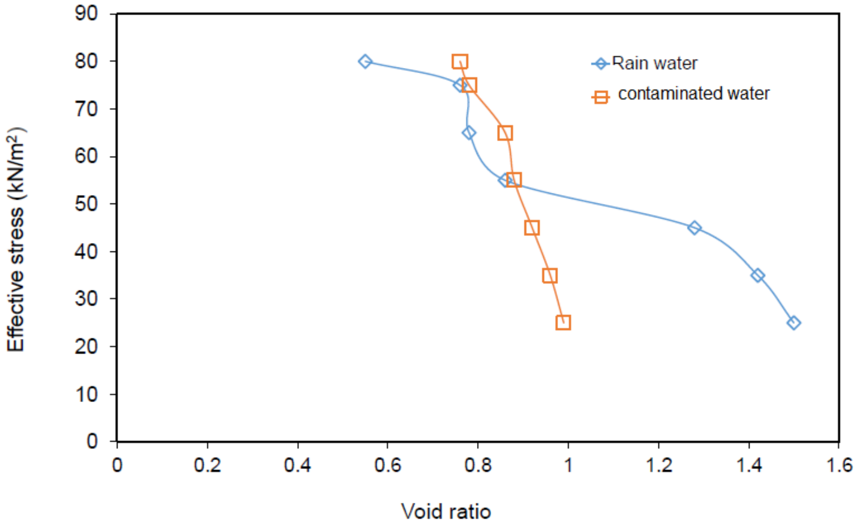
Figure 6. *Plot of Effective Stress versus Hydraulic Conductivity of Smectite Clay based on Rainwater and Contaminated Water*



There was a statistically significant difference in hydraulic conductivity between groups was determined by one-way ANOVA ($F(1,12)=5.43$, $p=0.038$). Hydraulic conductivity of the smectite clay based on rainwater as the control was higher than that based on contaminated water. Hydraulic conductivity of the smectite clay meets the requirements for a clay barrier (i.e., 1x 10^{-9} m/s or less). This characteristic is, however, in contrast with previous studies for hydraulic conductivity of geosynthetic clay liner that increased over time when permeated with acid rock drainage (Naka et al. 2012). This difference may be since this study was a short evaluation. A clay void ratio decreased as effective stress was increased. A void ratio based on rainwater was also, higher than that based on contaminated water (Figure 7). Some results for Atterberg limits are presented (Table 1). Atterberg limits decreased when the smectite clay has interacted with the contaminated water. An overall plasticity index of the smectite clay was, however, within the limits of 10-30% required for clay barriers.

From the experimental results, an uptake of the metal load contained in water was dependent on the chemical and geotechnical properties of the smectite clay. The smectite clay used in this study was a powdered type with a high specific surface area and high micron range particle size. The structure, chemical composition, exchangeable ion type, and small crystal size of smectite clays are several unique features that have influenced the chemical and geotechnical properties of the smectite clay.

Figure 7. *Plot of Consolidation versus Void Ratio based on Rainwater and Contaminated Water*



There was no statistically significant difference in void ratio between groups as determined by one-way ANOVA (F(1,12)=0.980, p=0.342). These properties include large chemically active surface area and a high cation exchange capacity. Because of these properties, the smectite clay used in this study was able to remove toxic metal ions in the contaminated water (Liu et al. 2018b). Therefore, this smectite clay hydrates uniformly from the outer surfaces towards the centre. These characteristics further, lower the hydraulic conductivity of the smectite clay used in this study (Liu et al. 2018b). These qualities result in the rapid development of an effective barrier system. The smectite clay generates high colloidal fraction when in contact with water and this characteristic enhances the adsorption characteristic of the smectite clay (Missana et al. 2018).

Performance of the Niger Delta Clay on the Bacteriology of the Contaminated Water

There was no statistically significant difference in bacterial removal between groups was determined by one-way ANOVA (F(4,5)=0.666, p=0.643). However, individual groups exhibited a non-statistically significant difference in bacterial removal. Elimination of the bacterial load took place by adhesion as provided in a previous study (Nandakumar et al. 2019, Dong 2012). The nature of the smectite clay surface and microbial cell surfaces are important in determining how some bacteria adhere to the smectite clay surfaces. This adhesion is a prelude to understanding the mechanism of removal of these bacteria from water (Liu et al. 2018b). An adhesion process was controlled by both chemical and physical interactions of the surface of the smectite clay and bacteria. An outcome of these contacts is dependent on a complex interaction between these bacteria and substrate surfaces.

Comparison of Performances

The smectite clay (Amelem) performed best as a bacteriological barrier, providing complete elimination of the E. *coli* in the contaminated water. The performance of this indicator is followed by the geotechnical characteristics of the smectite clay, thus providing a hydraulic conductivity of 1.6×10^{-10} m/s. The geochemical and adsorption characteristics of the smectite clay were pH-dependent, thus providing an adsorption efficiency of ≈95%.

Conclusions

In this study, a well-characterized locally sourced clay from the Niger Delta Region of Nigeria (Niger Delta Clay), was tested as a three-barrier system. The adsorption, geotechnical and bacteriological properties of the smectite clay provide statistically significant performance in the reduction of toxic heavy metals and bacterial load found in the Gbarain watershed of the Niger Delta Region of Nigeria. The findings reveal that the short-term evaluation of a simulated effluent indicated a reduction in toxic heavy metals and bacteriological load contained in contaminated-groundwater to safe limits based on WHO's standard.

Uptake of some inorganic pollutants by the smectite clay was found to be significant and increased with an increase in pH and dose of the adsorbent. The smectite clay, therefore, provided an excellent three- barrier system to the migration of metal load and bacteriological load contained in aqueous systems. This study was a 24-h short-term laboratory evaluation of properties related to the smectite clay as a 3-barrier system. Further studies would incorporate long-term lifetime or saturation time of the smectite clay.

Acknowledgments

The authors are grateful to the authority of the corresponding authors' institutions for the release of research allowances used for this project.

This research was funded by research allowances (SL20172018) provided by corresponding authors' Institution.

References

Abollino O, Aceto M, Malandrino M, Sarzanini C, Mentasti E (2003) Adsorption of heavy metals on Na-montmorillonite. Effect of pH and organic substances. *Water Research* 37(7): 1619–1627.

Agbozu IE, Oghama OE, Odhikori JO (2015) Physico-chemical characterization and pollution index determination of leachates from Warri waste dumpsite, Southern Nigeria. *Journal of Applied Sciences and Environmental Management* 19(3): 361–372.

Blott SJ, Pye K (2006) Particle size distribution analysis of sand-sized particles by laser diffraction: an experimental investigation of instrument sensitivity and the effects of particle shape. *Sedimentology* 53(3): 671–685.

Cantor KP, Villanueva CM, Silverman DT, Figueroa JD, Real FX, Garcia-Closas M et al. (2010) Polymorphisms in GSTT1, GSTZ1, and CYP2E1, disinfection by-products, and risk of bladder cancer in Spain. *Environmental Health Perspectives* 118(11): 1545–1550.

Chukwuma OM, Uchenna OF (2018) A comparative analysis of flooding in Warri and port Harcourt urban areas of the Niger Delta region in Southern Nigeria. *Arabian Journal of Geosciences* 11(8): 166.

D7263-09, ASTM (2018) *Standard test methods for laboratory determination of density (unit weight) of soil specimens*. USA.

Delavernhe L, Pilavtepe M, Emmerich K (2018) Cation exchange capacity of natural and synthetic hectorite. *Applied Clay Science* 151(Jan): 175–180.

Dong H (2012) Clay–microbe interactions and implications for environmental mitigation. *Elements* 8(2): 113–118.

Egirani DE, Poyi NR, Wessey N (2019) Synthesis of zinc oxide–montmorillonite composite and its effect on the removal of aqueous lead ions. *Acta Geochimica* 38(1): 120–130.

Fu F, Wang Q (2011) Removal of heavy metal ions from wastewaters: a review. *Journal of Environmental Management* 92(3): 407–418.

Fuller WH (2018) *Soils in waste treatment and utilization: volume i: land treatment*. CRC Press.

Ghazizadeh S, Bareither CA (2018) Stress-controlled direct shear testing of geosynthetic clay liners I: apparatus development. *Geotextiles and Geomembranes* 46(5): 656–666.

Hachich EM, Di Bari M, Christ APG, Lamparelli CC, Ramos SS, Sato MIZ (2012) Comparison of thermotolerant coliforms and Escherichia coli densities in freshwater bodies. *Brazilian Journal of Microbiology* 43(2): 675–681.

Hakan Ören A, Kul TÖ, Koç ME, Demirkıran H (2018) *Comparison of the hydraulic conductivity of GCLs with that of bentonitic mixtures*. Conference Paper. Geo-Chicago, August 2016, 358–367.

Izah SC, Bassey SE, Ohimain EI (2018) Ecological risk assessment of heavy metals in cassava mill effluents contaminated soil in a rural community in the Niger Delta region of Nigeria. *Molecular Soil Biology* 9(1): 1–11.

Kloprogge JT, Komarneni S, Amonette JE (1999) Synthesis of smectite clay minerals: a critical review. *Clays and Clay Minerals* 47(5): 529–554.

Liu P, Wang S, Ge L, Thewes M, Yang J, Xia Y (2018a). Changes of Atterberg limits and electrochemical behaviours of clays with dispersants as conditioning agents for EPB shield tunnelling. *Tunnelling and Underground Space Technology* 73(Mar): 244–251.

Liu JF, Ni HY, Chen YG, Wu Y, Song SB, Cao XL et al. (2018b) Research on water retention and microstructure characteristics of compacted GMZ bentonite under free swelling conditions. *Environmental Earth Sciences* 77(16): 583.

Madsen FT, Mitchell JK (1989) Chemical effects on clay farbric and hydraulic conductivity. In P Baccini (ed), *The Landfill. Lecture Notes in Earth Sciences.* Berlin, Heidelberg: Springer.

Missana T, Alonso U, Fernández AM, García-Gutiérrez M (2018) Colloidal properties of different smectite clays: significance for the bentonite barrier erosion and radionuclide transport in radioactive waste repositories. *Applied Geochemistry* 97(Oct): 157–166.

Misstear BD, Banks D, Clark L (2017) *Water wells and boreholes*. Chichester: John Wiley & Sons.
Murray HH (1999) Applied clay mineralogy today and tomorrow. *Clay Minerals* 34(1): 39–49.
Naka A, Katsumi T, Flores G, Inui T, Ohta T, Urakoshi T et al. (2012) Evaluation of mineral barriers against acid rock drainage. *Geotechnical Engineering Journal of the SEAGS & AGSSEA* 43(3): 35–42.
Nandakumar V, Huang C, Pulgar A, Balasubramanian V, Wu G, Chandar P et al. (2019) Particle assisted removal of microbes from surfaces. *Journal of colloid and Interface Science* 533(Jan): 190–197.
Ngang BU, Agbazue VE (2016) A seasonal assessment of groundwater pollution due to biochemical oxygen demand, chemical oxygen demand and elevated temperatures in Enugu northern senatorial district, south east Nigeria. *IOSR Journal of Applied Chemistry* 9(7): 66–73.
Odom IE (1984) Smectite clay minerals: properties and uses. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences* 311 (1517): 391–409.
Oluwapelumi OO (2015) Geotechnical characterization of some clayey soils for use as landfill liner. *Journal of Applied Sciences and Environmental Management* 19(2): 211–217.
Oyediran IA, Olalusi DA (2017) Hydraulic conductivity and leachate removal rate of genetically different compacted clays. *Innovative Infrastructure Solutions* 2(1): 46.
Rice EW, Baird RB, Eaton AD, Clesceri LS (2012) *Standard methods for the examination of water and wastewater*. Washington, DC, USA: American Public Health Association.
Scalia IVJ, Bohnhoff GL, Shackelford CD, Benson CH, Sample-Lord KM, Malusis MA et al. (2018) Enhanced bentonites for containment of inorganic waste leachates by GCLs. *Geosynthetics International* 25(4): 392–411.
Shafiq M, Alazba AA, Amin MT (2018) Removal of heavy metals from wastewater using date palm as a biosorbent: a comparative review. *Sains Malaysiana* 47(1): 35–49.
Shahadat M, Isamil S (2018) Regeneration performance of clay-based adsorbents for the removal of industrial dyes: a review. *RSC Advances* 8(43): 24571–24587.
Sipos P, Kis VK, Balázs R, Tóth A, Kovács I, Németh T (2018) Contribution of individual pure or mixed-phase mineral particles to metal sorption in soils. *Geoderma* 324(Aug): 1–8.
Tansel B, Yildiz BS (2011) Goal-based waste management strategy to reduce persistence of contaminants in leachate at municipal solid waste landfills. *Environment, Development and Sustainability* 13(5): 821–831.
Tong S, Shackelford CD (2016) Standardized hydraulic conductivity testing of compacted sand-bentonite mixtures. *Geotechnical Testing Journal* 39(6): 1015–1029.
Unuabonah EI, Ugwuja CG, Omorogie MO, Adewuyi A, Oladoja NA (2018) Clays for efficient disinfection of bacteria in water. *Applied Clay Science* 151(Jan): 211–223.
Velenturf AP, Jopson JS (2019) Making the business case for resource recovery. *Science of the Total Environment* 648(Jan): 1031–1041.
Xue M, Li J, Xu Z (2012) Environmental friendly crush-magnetic separation technology for recycling metal-plated plastics from end-of-life vehicles. *Environmental Science & Technology* 46(5): 2661–2667.
Zaki AA, Ahmad MI, El-Rahman KA (2017) Sorption characteristics of a landfill clay soil as a retardation barrier of some heavy metals. *Applied Clay Science* 135(Jan): 150–167.

Athens Journal of Sciences- Volume 7, Issue 4, December 2020 – Pages 225-240

DEEP: Extending the Digital Forensics Process Model for Criminal Investigations

By Jan Collie[*] & Richard E Overill[±]

The importance of high quality, reliable forensic analysis –an issue that is central to the delivery of justice– has become a topic for marked debate with scientists, specialists and government bodies calling for improved standards and procedures. At the same time, Law Enforcement agencies are under pressure to cut the cost of criminal investigations. The detrimental impact that this has had on all forensic disciplines has been noted internationally, with the UK's House of Lords warning that if the trend continues, crimes could go unsolved and miscarriages of justice may increase. The pivotal role that digital forensics plays in investigating and solving modern crimes is widely acknowledged: in Britain, the police estimate it features in 90% of cases. In fact, today's law enforcement officers play a key part in the recovery, handling and automated processing of digital devices yet they are often poorly trained to do so. They are also left to interpret outputs, with the results being presented in court. This, it is argued, is a dangerous anomaly and points to a significant gap in the current, four-stage digital forensics process model (DFPM). This paper presents an extension to that model, the Digital Evidence Enhanced Process (DEEP), with the aim of fine-tuning the mechanism and ensuring that all digital evidence is scrutinised by a qualified digital forensics analyst. The consequence of adopting DEEP in actual criminal investigations will be to ensure that all digital evidence is analysed and evaluated to the highest professional and technical competency standards, resulting in the enhanced reliability of digital evidence presented in court which will serve the cause of justice in terms of reduced instances of associated unsafe convictions and/or unjustified exculpations.

Keywords: *Digital forensics, forensic science, evidence processing, knowledge management*

Introduction

In the last ten years, no fewer than eight reports assessing the state of forensic science in England and Wales and offering recommendations to address the challenges have appeared (Tully 2015, 2018, 2019, Government Office for Science 2015, Science and Technology Committee 2011, 2013, 2018a, The Law Commission 2011). Two influential reports addressing similar issues have also been published in the United States (Committee on Identifying the Needs of the Forensic Science Community 2016, Executive Office of the President 2016). In Britain, concerns over the handling and disclosure of digital evidence by police became public three years ago after a number of rape trials collapsed and other

[*]Lecturer, The Open University, UK.
[±]Visiting Senior Research Fellow, Department of Informatics, King's College London, UK.

sexual assault cases were dropped when it was discovered that vital information on mobile phones had either been missed or had not been entered in prosecution evidence (Guardian 2019). An enquiry into these and other failures was quickly organised by the House of Commons Justice Committee with a range of specialist witnesses being called to give evidence (Justice Committee 2018). Among these was the Forensic Science Regulator (FSR), Dr Gillian Tully, who is tasked with regulating forensic science activities within the UK legal system (Tully 2017). Following earlier testimony from a digital forensic practitioner pointing out that front-line police officers, with little or no training in digital forensics, were making interpretations of evidential outputs that then went before courts, the FSR agreed: "One of the big issues that I see… is that the digital forensics units are quite good at keeping up to date with technology for extracting data and making copies, but they then pass the copies, largely uninterpreted, to police officers, who are not experts and who are not digital forensics people. General policing investigators do not necessarily have the tools to search that information effectively and understand it". She added that digital forensics now pervades almost every aspect of policing. "Frontline officers are doing all sorts of different types of what we would formerly have called digital forensics, so there is an issue with how you get any form of control over something that is so pervasive throughout all of policing".

A later enquiry was held by the House of Lords' Select Committee on Science and Technology, which also heard oral evidence (Science and Technology Committee 2018b). During one session, the Head of the Metropolitan Police's Digital, Cyber and Communications Forensics Unit, Mark Stokes, estimated that, including cases involving CCTV, communications data, social media data and cyberattacks, around 90% of crime has a digital element. He made an equally high estimate for most fraud, murder and complex rape cases. Stokes described today's police officers as "digital natives" who could use social media and current technology but they did not know the constraints and limitations of that technology. He acknowledged that: "Training on what should be seized and how it should be handled is absolutely critical and there is a lack of that". A core part of police training should be around the digital world, he added.

Enquiries by both houses of Parliament concluded that urgent reforms were necessary. A report from the House of Commons Justice Committee stated: "It is clear, from the evidence that we have heard, that the growth in digital material presents a challenge to police and prosecutors. We believe that police forces are not always adequately equipped or properly trained to handle the type and volume of evidence that they now routinely collect and that this can lead to errors when reviewing and disclosing material and therefore has the potential to lead to miscarriages of justice" (Justice Committee 2018).

A report from the House of Lords gave the forceful view that all forensic science in the UK "is in a state of crisis" due to an absence of high-level leadership, a lack of funding and an insufficient level of research and development. It warned: "The delivery of justice depends on the integrity and accuracy of forensic science evidence and the trust that society has in it" (Science and Technology Committee 2019).

Although the House of Lords has highlighted the danger posed to justice by inadequacies in forensic science in general and the House of Commons has done the same in respect of digital forensics in particular, no call has been made by these or other authorities to stop or alter the current practice of allowing regular police officers to either perform forensic procedures on digital devices or to attempt to interpret the outputs. Law enforcement agencies have been subject to severe budget cuts over a number of years, leading to a lack of resources and appropriately trained personnel. Extending the remit of front-line officers into the performance of specialist tasks can be seen as one of many cost-cutting exercises. The authors do not believe that this situation is acceptable, but it is nevertheless what currently exists and, given the current financial climate, what is likely to persist. A solution is clearly necessary if the cause of justice is to be better served. A step towards achieving that solution, we suggest, is to implement a more informed method of processing digital evidence.

Literature Review

Digital Evidence: The Need for Accurate Analysis

The findings made by both the House of Commons and House of Lords confirm and validate the opinions expressed by practitioners and academics in the field of digital forensics. Stressing the potential impact on a person's livelihood or liberty, Casey et al. (2018) asserted that the ability to interpret digital evidence accurately is crucial in order to "avoid mistakes, missed opportunities, misinterpretations and miscarriages of justice". Similar points have been made by Collie (2018), who commented, "Digital forensics is meant to be based on science, not supposition… And in every case, somebody's freedom is at stake". Both Casey and Collie have raised concerns over the handling of digital devices by police with minimal training.

"Typically, police with limited digital forensic expertise have the initial responsibility to recognize sources of digital traces and to apply basic preservation and processing methods. They are at high risk of not realizing limitations in the methods and tools that are available to them, leading to mistakes and missed opportunities" Casey (2019) says, adding that this is due to "gaps in knowledge". The risk continues to increase because of the "dynamic nature of cybercrime and technology".

Collie (2018) has highlighted the every-day situation in the UK, where a suspect's mobile phone is frequently given to a police officer with minimal training to perform a download. The results from the forensic tool used for the extraction, "will be handed to someone with even less or, more likely, absolutely nil training in digital forensics: the Officer in Charge of the case (OIC). S/he will look at the outputs… whatever they make of it will go before the court".

Shaw and Browne (2013) have also drawn attention to the risks involved when inadequately trained personnel perform a "technical" triage i.e., use a commercial forensic tool to target potential evidential data on some digital device.

One danger is that the resulting outputs may easily be misinterpreted. Reviewing outputs from this type of automated process requires a "fairly high degree of knowledge and experience of digital forensics", the authors say. However, the focus of their research is the development of an enhanced previewing system since they assert, given the vast amount of data that is now typically submitted for examination, that the primary concern of the digital forensics community is that evidential data may be overlooked if some exhibits are excluded.

The use of enhanced previewing to assist decision making when assessing exhibits has been considered by James and Gladyshev (2013), too, and found effective. The authors examined the accuracy of forensic examiners' personal choices when including or excluding exhibits, which were based on experience, as well as the accuracy of automated tools. Overill et al. (2013) have further proposed developing triage template pipelines as a way of narrowing down the volume of data needing full forensic examination. The approaches discussed above are based primarily on improving efficiency rather than quality.

Screening seized devices for the existence of relevant evidence constitutes survey or triage for some authorities and preliminary forensic examination for others. Indeed, the very meaning of the word "triage" has been a matter for debate. In this paper, we follow Casey et al. (2013) in defining the triage process as the: "early extraction of information from digital evidence sources". Casey et al. (2013) also stress the importance of promoting efficiency throughout a whole digital forensic investigation. This means making the most of limited resources, giving support for key decisions at key points and increasing the quality of findings – all aspirations that we aim towards with our proposed model.

Confirmation Bias

As Shaw and Browne (2013) observed, there is a propensity to misinterpret data when inadequately trained personnel try to interpret outputs from digital forensic downloads. Collie (2018), too, has pointed out that an OIC may choose to stress certain aspects of evidence above others if they appear to be useful to the case in hand. One example of an OIC "cherry picking" particular words from web browsing outputs from a mobile phone in support of a criminal charge and also confusing browsing results with user search results was related by Collie to the House of Commons' Justice Committee.

The risk of confirmation bias has also been raised by Casey (2018) who commented: "When forensic examiners concentrate on proving or disproving a specific claim, there can be a risk of confirmatory bias. To mitigate the risk, an increasing number of best practice guidelines are instructing forensic practitioners to evaluate the probability of evidence given on claim versus a given alternative claim".

Casey (2019) again remarked that: "Roles, responsibilities, rewards, plus selection, training and culture all have a major influence on the objectivity of investigators and forensic specialists". Adding: "Without formalized independence of digital forensics in the investigative process, it is difficult to maintain scientific objectivity of the results".

Sunde and Dror (2019) have further emphasised the issue of cognitive bias as a source of error in digital forensics. Extensive research has shown that forensics experts are susceptible to bias when making decisions, they report, advocating that practitioners should test and eliminate multiple and preferably competing hypotheses when conducting examinations. This injunction echoes the recommendation made in the FSR's codes of practice and conduct (2016), that alternative hypotheses should be considered when analyzing cell site evidence.

Sunde and Dror (2019) conclude that bias cannot be totally eliminated but procedures to uncover cognitive or human errors are necessary. One means of achieving this would be to have forensic advisors involved throughout the investigative process, as Casey (2019) suggests. This is an issue which we also seek to address since the model we propose aims to maximise input from qualified examiners during the existing triage process.

Citing the problems identified by these and other authors, Horsman (2019) has noted that there is a lack of dedicated research and formalisation of investigative decision-making models to support digital forensic practitioners. He has proposed a framework designed to help practitioners at all levels to assess the reliability of their "inferences, assumptions and conclusions". Whilst taking numerous aspects of the decision-making process and quality management into account, the model is very complex. It also does not address the immediate problems faced by front-line law enforcement officers in handling and assessing digital evidence. The present paper suggests that the existing four-stage DFPM should be extended to include a routine that improves the model currently employed by law enforcement (LE) when processing digital evidence and helps ensure that data outputs and any deductions drawn from them are checked by a qualified analyst before being presented in a statement or report for court. In the proposed model, both the interpretation of data, i.e., understanding what events occurred and the evaluation of data, whether qualitative or quantitative, is taken to be carried out by a digital forensic examiner. The choice of evaluation methodology is a point for further research and debate and falls outside the remit of this paper.

Digital Forensic Processing - Best Practice, Triage and Current Model

Best-practice methods for collecting and securing digital devices have been laid out in numerous guides, the majority produced by LE and government agencies. These include the well-known Association of Chief Police Officers (ACPO) guidelines, first published in 1999 and last updated in 2012. In common with other published guides in this subject area, for example, First Responder reference works published by the U.S. Department of Justice (2008) and the U.S. Secret Service (2009), the ACPO guidelines are primarily aimed at serving officers but are also taken to apply to investigators and practitioners of digital forensics in the private sector. Most of the guides written for LE agencies do not cover the subsequent analysis of data, although the 2012 version of the ACPO guide does contain a brief section, giving views on who should carry out digital forensic analysis and the need for that analysis to be properly targeted towards gathering evidence relevant to the case in hand.

The four aims of the digital forensic process, as identified from these guidelines and in order of importance are to:

1. Identify the evidence.
2. Preserve the evidence.
3. Recover the evidence.
4. Present the evidence.

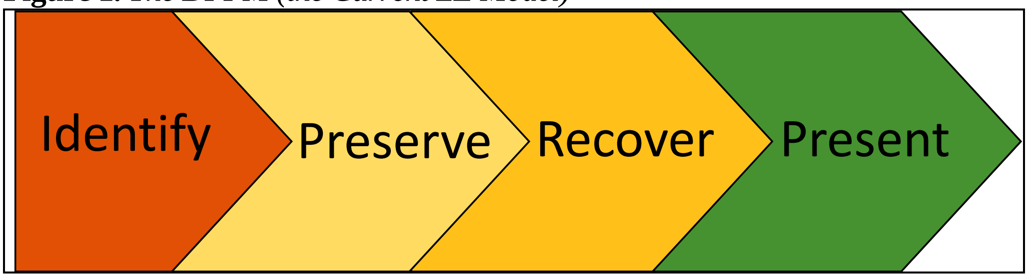
In the above context, "Identify" is taken to mean "know where digital evidence is likely to reside", i.e., on a computer, mobile phone, tablet, etc.

In a business-oriented rendering, von Solms et al. (2006) have listed the four key activities of the digital forensic process as:

1. Securing the evidence without contaminating it.
2. Acquiring the evidence without altering or damaging the original.
3. Authenticating that the recovered evidence is the same as the original seized data.
4. Analysing the data without modifying it.

A visual encapsulation of the process commonly employed LE is given in Figure 1. This is the model which we suggest should be modified and enhanced.

Figure 1. *The DFPM (the Current LE Model)*



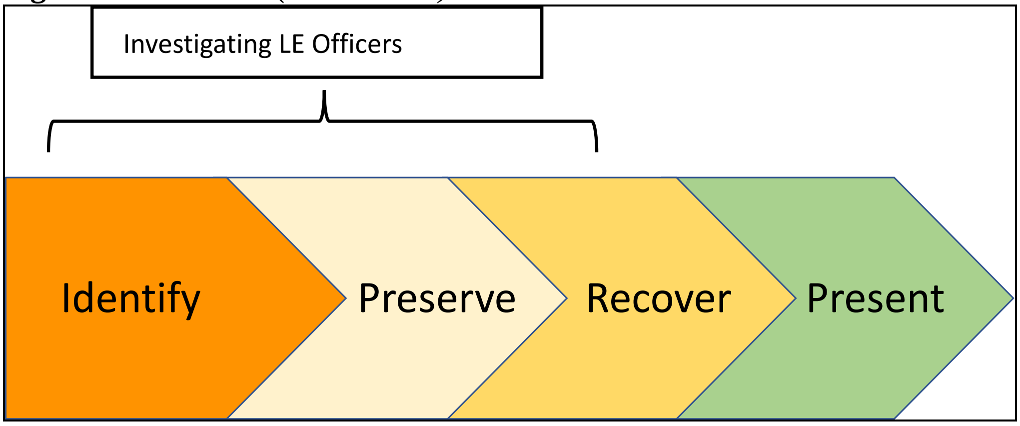
Methodology

In this section we demonstrate the methodological development of the DFPM into DEEP in a series of evolutionary steps.

Embellished DFPM

In some crime-related investigations, police officers are tasked with carrying out the first two parts of this process, namely: identifying devices of potential evidential interest and preserving them. In others, particularly those involving mobile phones, they can be tasked with the first three parts of the process, the additional task being to recover data from a digital device. The DFPM can be developed to include this feature, as shown in Figure 2.

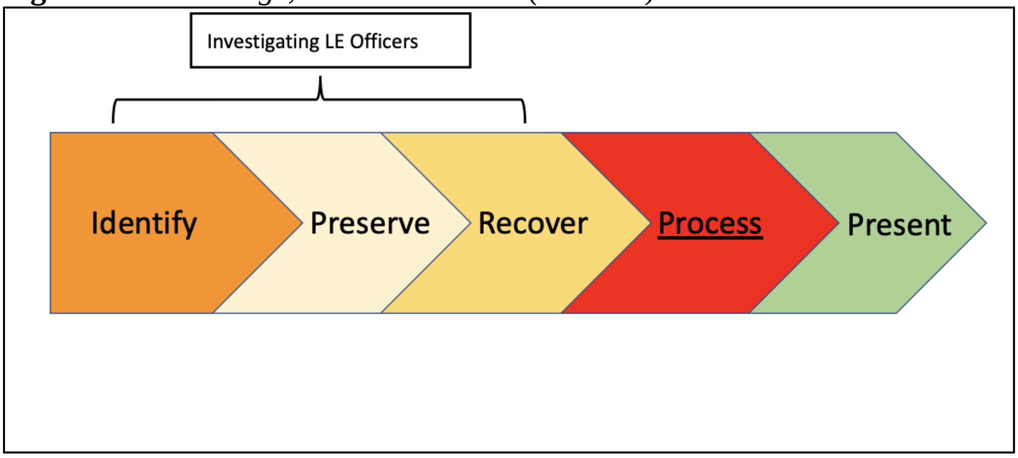
Figure 2. *The DFPM (Embellished)*



It should be noted here that an investigating officer may either hand on a device (such as a mobile phone) to another officer who has received some training in recovering data using a "kiosk" forensic solution, or they may have been trained to do this themselves. In an alternative scenario, usually one where computer equipment is seized, the device will be passed to a person who is properly trained to digitally image the equipment. A digital forensic analyst will then examine the image and produce a brief report of findings known as a Streamlined Forensic Report (SFR). The investigating officer may then use an automated, proprietary forensic tool on the image to look for specific activity, e.g., web-browsing.

Whichever is the case, as has been discussed in the proceeding sections, we suggest that a logical knowledge gap occurs at this point in the DFPM, between the final two stages. We label that gap "Process" and generate an enhanced model (EDPM), illustrating this in Figure 3.

Figure 3. *A Five-Stage, Enhanced DFPM (EDFPM)*



Enhanced DFPM

Using this new five-stage model, the current method of working used by LE and discussed above, can be rendered as in Figure 4. In this illustration, "Officer 1" may be the investigating officer or an officer trained to recover data using a kiosk solution. Once a data download from a mobile phone is obtained, any results gained are passed to the Officer in Charge of the case (OIC). Thus, a knowledge gap occurs because, in the case of mobile phones, a qualified analyst may never see any outputs from the device before an attempt at interpretation is made. With computers, a knowledge gap occurs because a qualified analyst carries out only a brief examination of the data and produces an SFR. This short, undetailed report of findings, goes to the OIC who tries to draw inferences from it. An SFR is intended to be for the information of both the OIC, to decide if there is enough evidence to support the charge made, and the solicitor for the defence, to decide whether the evidence should be challenged or whether the defendant should be advised to enter a guilty plea. An SFR is not intended to go before a court unless the findings are agreed between the prosecution and the defence sides.

Figure 4. *Current LE Processing Method: The Knowledge Gap*

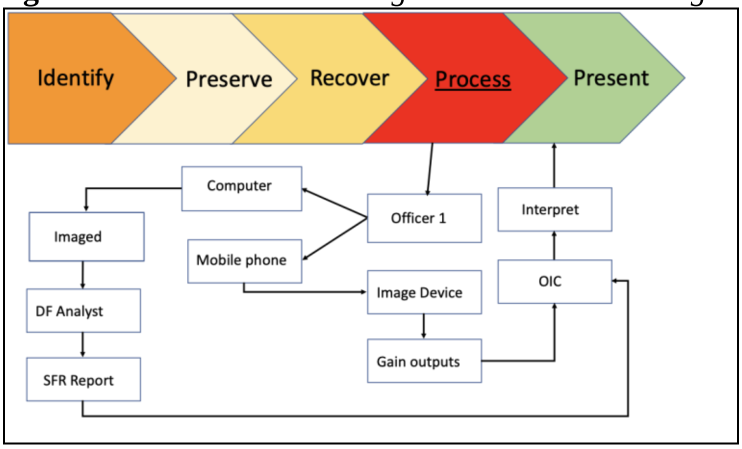


Figure 5. *DEEP – Its Location in the EDFPM*

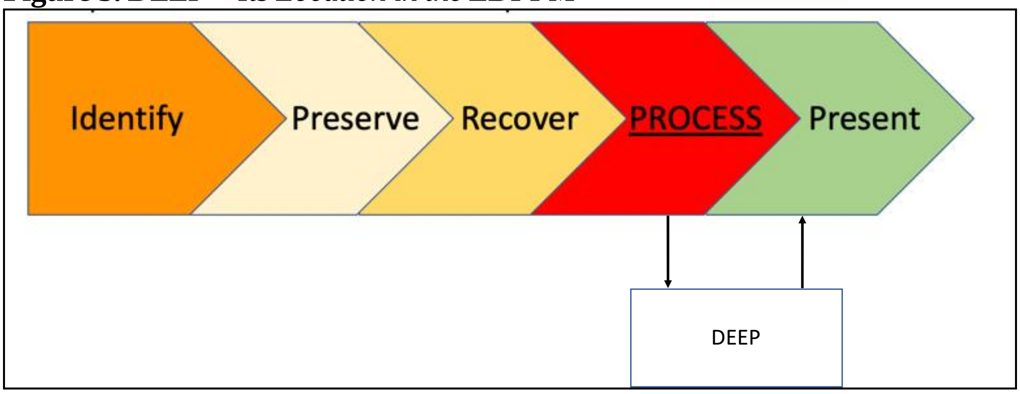
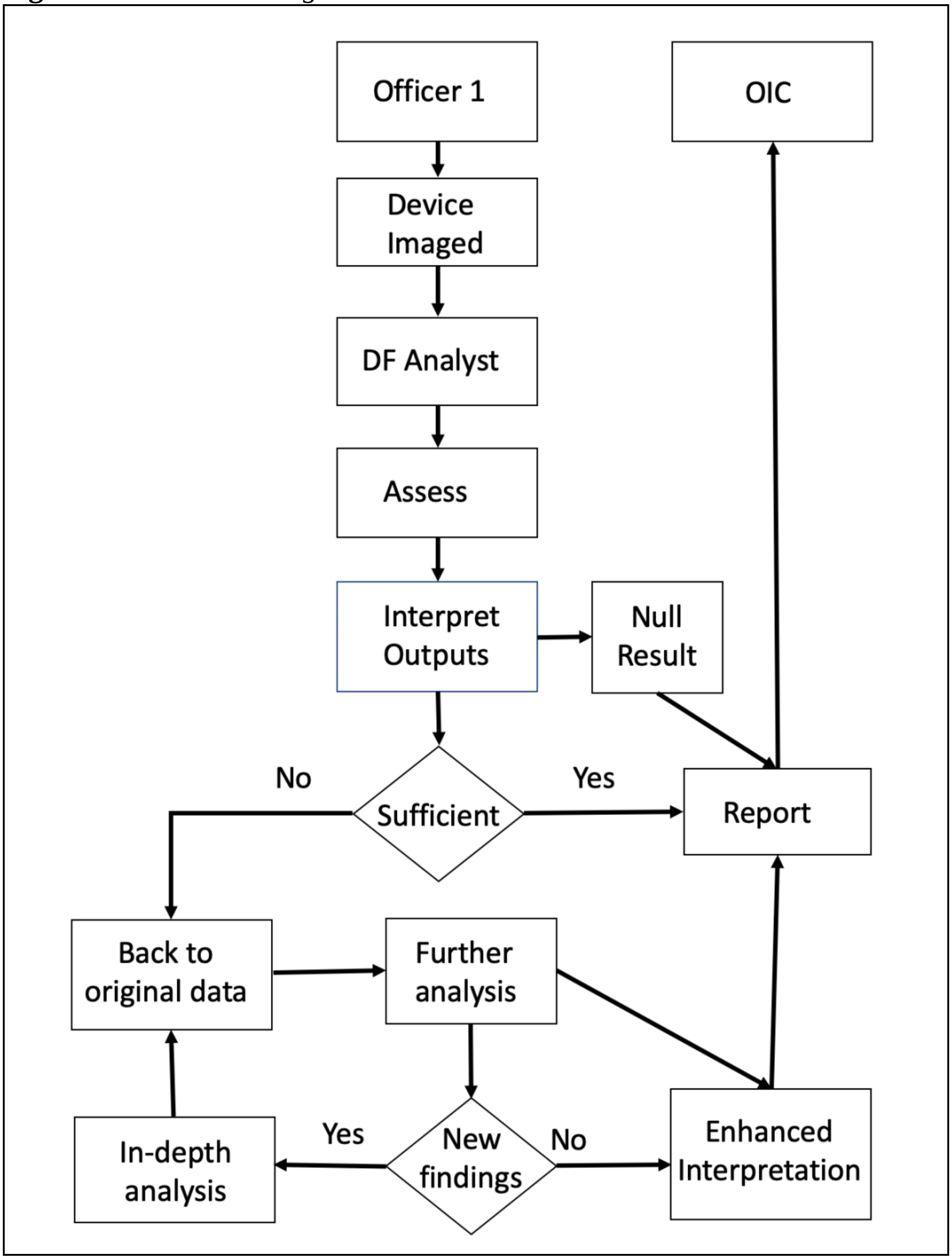


Figure 6. *DEEP – The Digital Evidence Enhanced Model*



Digital Evidence Enhanced Process (DEEP)

We now introduce a model for DF processing which has been derived from assimilating and analysing the research literature discussed earlier in this paper and by considering the system that is currently in used by LE in the UK. The model is termed Digital Evidence Enhanced Process (DEEP), and fits into the enhanced five-stage EDFPM, illustrated in Figure 3, at our proposed new fourth (Process) stage (see Figure 5). It replaces the method illustrated in Figure 4 with that shown in Figure 6, and aims to fill the knowledge gap that occurs when an OIC untrained in digital forensics is passed (a) outputs from an automated download or (b) an SFR, by ensuring that data of potential evidential interest is scrutinised and interpreted by a trained DF analyst before being passed to an OIC. When a trained DF analyst decides that the outputs acquired so far are sufficiently convincing to make an informed report in the light of the current enquiry, a straightforward path is followed. However, if the trained DF analyst decides that the currently available outputs are insufficient to support an informed report, a loop is entered in which the analyst goes back to the original data. At this point, it may be the case that further analysis of the original data allows an enhanced interpretation of the original findings to be made. Alternatively, new findings that require further in-depth analysis may be made. A report is produced once all the outputs relevant to the enquiry are sufficiently well explained. Note that, although the title "DF Analyst" appears explicitly only once in Figure 6, it is in fact implicit in the DEEP model that the DF analyst is also involved in the whole of the cycle that is concerned with returning to the original data for further analysis.

Results and Discussion

In this section we demonstrate how our proposed DEEP model operates in a typical scenario based on an actual criminal case with which one of the authors was professionally involved as a digital forensic investigator, in order to display its advantages over the DFPM. This case study provides an illustrative validation of the merits of DEEP over the DFPM.

Typical crime scene scenario: a police officer arrests a suspect at the scene of a crime. The suspect is carrying one phone which the officer takes into custody. Later, at the police station, the officer connects the phone to a "kiosk" facility, which contains the necessary hardware and software to:

a) Obtain a data dump from the phone.
b) Interrogate the data and filter it into categories e.g., messages, web browsing history.
c) Run a keyword search across the data.

The first officer completes steps a) and b) and then gives the outputs from the initial interrogation to the OIC. Using the same software tool as the first officer, the OIC runs a keyword search across the data set. Evidence of potential interest to the enquiry is found in web browsing outputs. This consists of pornographic words and phrases.

The offence that the suspect has been arrested in connection with relates to a claim of child abuse, brought to police attention by the mother and involving a child of the suspect's family. The OIC has seen words and phrases that suggest both an interest in indecent images of children and an interest in incestuous relationships. The OIC has seen words and phrases that suggest both an interest in indecent images of children and an interest in incestuous relationships. Between 10 to 12 words suggestive of the suspected offence have been found in the majority of rows of a table of outputs produced by the forensic software tool used. The OIC concludes that these are search terms that have been entered into the web browser by the suspect and writes a report for court to that effect.

If the loop stops here, as happens in the existing processing model, the OIC's report goes before the court without further question with the high likelihood of a conviction being handed down by the judge and jury.

If, as in the DEEP model, the phone data dump is passed to a digital forensic analyst to assess and a proper interpretation of the outputs is made at this stage, it will be discovered that the web browser artefacts are not actually search terms but keywords picked up by the browser from the descriptions of content that is hidden in the webpage's HTML code. The keywords are associated with video loop click-throughs that are sited on the pornography web site's main page. These would lead to full-length video content if a user clicked on the links. However, the video loop shorts are content that runs automatically when a user lands on the web site, the user does not actively choose to view the content unless they click the associated link. Furthermore, the keywords associated with the content do not reflect the particular search terms entered by the user into the browser before landing on the pornography website's main page. These findings have important legal implications.

The value of DEEP is further demonstrated when other outputs from the illustrative case used in the above case study are considered.

Figure 7 below is a sample of data which consists of outputs from web browsing activity which has taken place on a mobile phone. It will be seen that the final column contains the source of the data and the third column to the left contains dates and times. Both are revealing to the digital forensic analyst. In this instance, the source is the Chrome browser installed on the mobile phone. Reading from the top down, the dates for the top four outputs (numbered 52–56 in the far left hand column) are all the same, the next recorded time is 1 second earlier, the next recorded time one second before that and the final three times, two seconds before that. What this tells a trained analyst is that this is not browsing activity carried out by the user of the mobile phone –clearly, no one can type an entire phrase in one to two seconds– but system activity which occurs automatically in the background.

Compare the foregoing with Figure 8 below, where the source (final column) is again the Chrome browser. However, the marking 'synced data' will be seen. This means that the activity concerned did not occur on the mobile phone in question but on some other device which synchronises with a shared cloud-based service. Thus, it cannot be said that the device user carried out this activity. It can also be seen that the dates and times, in the third column to the left, vary, in a pattern which is indicative of normal user activity.

(Note that Figures 7 and 8 contain words and phrases of a sexual nature which some readers may find offensive).

Figure 7. *Initial Analysis*

52	Gozada gostosa - XNXX.COM	https://www.xnxx.com/video-7lm9z5d/gozada_gostosa	28/09/2017 06:29(UTC+0)		Chrome **Source Extraction:** File System
53	VID-20160419-WA0129 - XNXX.COM	https://www.xnxx.com/video-c8tbn27/vid-20160419-wa0129	28/09/2017 06:29(UTC+0)		Chrome **Source Extraction:** File System
54	Gostosa não aguentou cair na rola e esguichou - XNXX.COM	https://www.xnxx.com/video-ejblv3b/gostosa_nao_aguentou_cair_na_rola_e_esguichou	28/09/2017 06:29(UTC+0)		Chrome **Source Extraction:** File System
55	Se não matou, mandou para o hospital - XNXX.COM	https://www.xnxx.com/video-98nv1b2/se_nao_matou_mandou_para_o_hospital	28/09/2017 06:29(UTC+0)		Chrome **Source Extraction:** File System
56	Gostosa não aguentou cair na rola e esguichou - XNXX.COM	https://www.xnxx.com/video-ejblv3b/gostosa_nao_aguentou_cair_na_rola_e_esguichou	28/09/2017 06:29(UTC+0)		Chrome **Source Extraction:** File System
57	Puta não quenta a rola grossa do negão, goza e se mija toda. - XNXX.COM	https://www.xnxx.com/video-fs6nh6e/puta_nao_quenta_a_rola_grossa_do_negao_goza_e_se_mija_toda.	28/09/2017 06:28(UTC+0)		Chrome **Source Extraction:** File System
58	Gostosa não aguentou cair na rola e esguichou - XNXX.COM	https://www.xnxx.com/video-ejblv3b/gostosa_nao_aguentou_cair_na_rola_e_esguichou	28/09/2017 06:27(UTC+0)		Chrome **Source Extraction:** File System
59	VID-20160419-WA0129 - XNXX.COM	https://www.xnxx.com/video-c8tbn27/0/vid-20160419-wa0129	28/09/2017 06:25(UTC+0)		Chrome **Source Extraction:** File System
60	VID-20160419-WA0129 - XNXX.COM	https://www.xnxx.com/video-c8tbn27/vid-20160419-wa0129	28/09/2017 06:25(UTC+0)		Chrome **Source Extraction:** File System
61	Darmowe porno, seks, źródło filmów, zdjęcia XXX, cipka w filmach porno - XNXX.COM	https://www.xnxx.com/	28/09/2017 06:25(UTC+0)		Chrome **Source Extraction:** File

Figure 8. *In-Depth Analysis*

7	Auto Trader UK - New & used cars for sale	https://www.autotrader.co.uk/	11/09/2017 13:31(UTC+0)		Chrome : synced data: NEM-L51 **Source Extraction:** File System		High
8	Allegro.pl - Więcej niż aukcje. Najlepsze oferty na największej platformie handlowej.	https://allegro.pl/	11/09/2017 07:01(UTC+0)		Chrome : synced data: NEM-L51 **Source Extraction:** File System		High
9	Darmowe porno, seks, źródło filmów, zdjęcia XXX, cipka w filmach porno - XNXX.COM	https://www.xnxx.com/	29/08/2017 06:15(UTC+0)		Chrome : synced data: NEM-L51 **Source Extraction:** File System		High
10	Darmowe porno, seks, źródło filmów, zdjęcia XXX, cipka w filmach porno - XNXX.COM	https://www.xnxx.com/	28/08/2017 18:15(UTC+0)		Chrome : synced data: NEM-L51 **Source Extraction:** File System		High
11	Flightradar24.com - Live flight tracker!	https://www.flightradar24.com/WZZ1JK/ea4e6d8	28/08/2017 06:45(UTC+0)		Chrome : synced data: NEM-L51 **Source Extraction:** File System		High
12	Tanie loty - Tanie latanie - Rezerwacja tanich lotów - eSky.pl	https://www.esky.pl/bilety-lotnicze?gclid=Cj0KCQjw24nNBRChARIsALldLD36H09B1pAzcEMJtpwQOZBTu8pjg_BtQ89KiJIUyTSOStMUoSW5JXcaAtcKEALw_wcB	28/08/2017 05:10(UTC+0)		Chrome : synced data: NEM-L51 **Source Extraction:** File System		High

Summary and Conclusions

The application of forensic science in the criminal justice system has reached a crisis point. This applies to all forensic disciplines, but the spotlight has fallen on digital forensics in particular during the past two years. In the UK, concerns have been raised over the handling and disclosure of digital evidence by LE and, in several well-publicised instances, court cases have been stopped or dropped as a result of failures in the system. Enquiries have been conducted by both the House of Commons and the House of Lords, both of which identified a lack of high quality and robust analysis, with a consequent detrimental impact on justice, and called for urgent improvements.

Digital forensics plays a central role in the detection, investigation and solving of crimes. At the fore-front of the detection process, tasked with the recovery of devices that may contain data of evidential interest, are today's law enforcement officers. Increasingly, where mobile phones are concerned, these devices are passed to officers with little or no training in digital forensics for download. The resulting output reports are passed on to other untrained officers. While computers are normally imaged and analysed by specialists, only brief findings are passed on to investigators. As a result of this anomaly, authorities in digital forensics have highlighted that mistakes and misinterpretations are made, potentially leading to miscarriages of justice. At the heart of this anomaly is a knowledge gap that needs to be filled.

A four-stage DFPM model has previously been used to encapsulate the aims of the digital forensic process. This paper proposes that a fifth stage is necessary. This stage slots into the existing DFPM model at the point where investigating officers put digital devices into forensic processing. The current LE *modus operandi* is modelled in order to identify where knowledge gaps occur. A new model, DEEP, is proposed with the aim of improving and enhancing the LE process by ensuring that data of potential evidential interest is both seen and interpreted by a trained DF analyst before being passed to an OIC.

The DEEP model has been carefully validated using a typical real-world crime scenario drawn from an actual digital forensic investigation conducted by one of the authors, and has been demonstrated to enable additional digital evidence to be uncovered whose evaluation and interpretation significantly changes the view of the case. Our contention is therefore that if DEEP were to be routinely in operation during criminal investigations, the risk of miscarriages of justice (both unsafe convictions and unjustified exculpations) would be reduced and the cause of justice served.

References

Casey E, Katz G, Lewthwaite J (2013) Honing digital forensic processes. *Digital Investigation* 10(2): 138–147.

Casey E (2018) Clearly conveying digital forensic results. *Digital Investigation* 24(Mar): 1–3.

Casey E, Geradts Z, Nikkel B (2018) Transdisciplinary strategies for digital investigation challenges. *Digital Investigation* 25(Jun): 1–4.

Casey E (2019) The chequered past and risky future of digital forensics. *Australian Journal of Forensic Sciences* 51(2): 1–16.

Collie J (2018) Digital forensic evidence - Flaws in the criminal justice system. *Forensic Science International* 289(May): 154–155.

Committee on Identifying the Needs of the Forensic Science Community (2016) *Strengthening forensic science in the United States: a path forward*. National Research Council of the National Academies. Retrieved from: https://www.ncjrs.gov/pdffiles1/nij/grants/228091.pdf. [Accessed May 2019].

Executive Office of the President (2016) *Forensic science in criminal courts: ensuring scientific validity of feature-comparison methods*. President's Council of Advisors on Science and Technology. Retrieved from: https://bit.ly/3gIPE3b. [Accessed October 2019].

Government Office for Science (2015) *Forensic science and beyond: authenticity, provenance and assurance, annual report of the government chief scientific adviser 2015*. Retrieved from: https://bit.ly/2ALZa6z. [Accessed October 2019].

Guardian Online (2018) *London rape trial collapses after phone images undermine case*. Retrieved from: https://bit.ly/2CnRgAw. [Accessed April 2019].

Horsman G (2019) Formalising investigative decision making in digital forensics: proposing the Digital Evidence Reporting and Decision Support (DERDS) framework. *Digital Investigation* 28(Mar): 146–151.

James JI, Gladyshev P (2013) A survey of digital forensic investigator decision processes and measurement of decisions based on enhanced preview. *Digital Investigation* 10(2): 148–157.

Justice Committee (2018) *Oral evidence: disclosure of evidence in criminal cases, HC859.* Questions 173–217. Retrieved from: https://bit.ly/2BMDaJl. [Accessed May 2019].

Overill RE, Silomon JAM, Roscoe KA (2013) Triage template pipelines in digital forensic investigations. *Digital Investigation* 10(2): 168-174.

Science and Technology Committee (2011) *The forensic science service*. Seventh Report, Session 2010–12, HC 855. Retrieved from: https://bit.ly/38N3oHt. [Accessed October 2019].

Science and Technology Committee (2013) *Forensic science*. Second Report, Session 2013–14, HC 610. Retrieved from: https://bit.ly/2ZfcoCd. [Accessed October 2019].

Science and Technology Committee (2018a) *Biometrics strategy and forensic services*. Fifth Report, Session 2017–19, HC 800. Retrieved from: https://bit.ly/3ehDLj4. [Accessed October 2019].

Science and Technology Committee (2018b) *Corrected oral evidence: forensic Science*. Questions 123–131. Retrieved from: https://bit.ly/38MrYse. [Accessed May 2019].

Science and Technology Committee (2019) *Forensic science and the criminal justice system: a blueprint for change*. Retrieved from: https://bit.ly/2ZgW3wN. [Accessed May 2019].

Shaw A, Browne A (2013) A practical and robust approach to coping with large volumes of data submitted for digital forensic examination. *Digital Investigation* 10(2): 116–128.

Sunde N, Dror IE (2019) Cognitive and human factors in digital forensics: problems, challenges, and the way forward. *Digital Investigation* 29(Jun): 101–108.

The Law Commission (2011) *The admissibility of expert evidence in criminal proceedings in England and Wales*. Consultation Paper No 190. Retrieved from: https://bit.ly/2Oe0OB4. [Accessed May 2019].

Tully G (2015) *Annual report November 2014–November 2015.* Forensic Science Regulator. Retrieved from: https://bit.ly/3fhBHJs. [Accessed October 2019].

Tully G (2017) *Annual report November 2015–November 2016.* Forensic Science Regulator. Retrieved from: https://bit.ly/3eghoe2. [Accessed May 2019].

Tully G (2018) *Annual report November 2016–November 2017*. Forensic Science Regulator Forensic Science Regulator. Retrieved from: https://bit.ly/38H6kFu. [Accessed October 2019].

Tully G (2019) *Annual report November 2017–November 2018*. Forensic Science Regulator. Retrieved from: https://bit.ly/3fbLO2i. [Accessed October 2019].

von Solms S, Louwrens C, Reekie C, Grobler T (2006) A control framework for digital forensics. In *Advances in Digital Forensics II, IFIP Advances in Information and Communication* 222, 343–355. Boston: Springer.

Athens Journal of Sciences- Volume 7, Issue 4, December 2020 – Pages 241-266

Geostories: A New Landscape-Ring between Italy, Slovenia and Austria

By Adriano Venudo[*]

The research investigates the border between Italy, Slovenia and Austria which is part of a wider system, on a continental scale: the European Green Belt which stood on the border of the "iron curtain". This research uncovered a "landscape-ring", a large cross-border ring, which contains a sort of "border region" that no one had yet identified. It is an autonomous entity, although belonging to the three states. The "landscape-ring" is made up of pieces of existing infrastructure belonging to other systems, but which represent, within the ring around the border, an "important" new infrastructure serving the territory. It also represents a functional unit (landscape, environmental, settlement, community), a perception system, in a few words an entire structural unit for the border region.

Keywords: *Landscape, infrastructure, mobile border, mutation ecology, Italy, Austria, Slovenia*

Introduction

Border as Landscape

This article summarises the findings of a research conducted by the author in collaboration with Giovanni Fraziano, Thomas Bisiani, Luigi Di Dato, Claudio Menino, Valentina Rodani, and Marko Verri, teachers of the Univeristy of Trieste and Špela Hudnik, visiting professor and teacher at University of Lubljana. The research focused on the "big change" ongoing along the Italian, Austrian and Slovenian border, following the geo-political developments of the last 20 years.

The research area is set along the Italian, Slovenian and Austrian border, in north-eastern Italy, from the mountains of Carnic Alps to the Adriatic Sea shore. Here, the national border runs for 180 km and above an extended area of 7000km^2 (Figure 1), which has been also included in the study site, and represents a "landscape-unit" (Figure 4), stratified with history and traditions of the communities that inhabit it (rhythm and fluxes), and represents a territory with a unique potential for the development of new projects (Geographies).

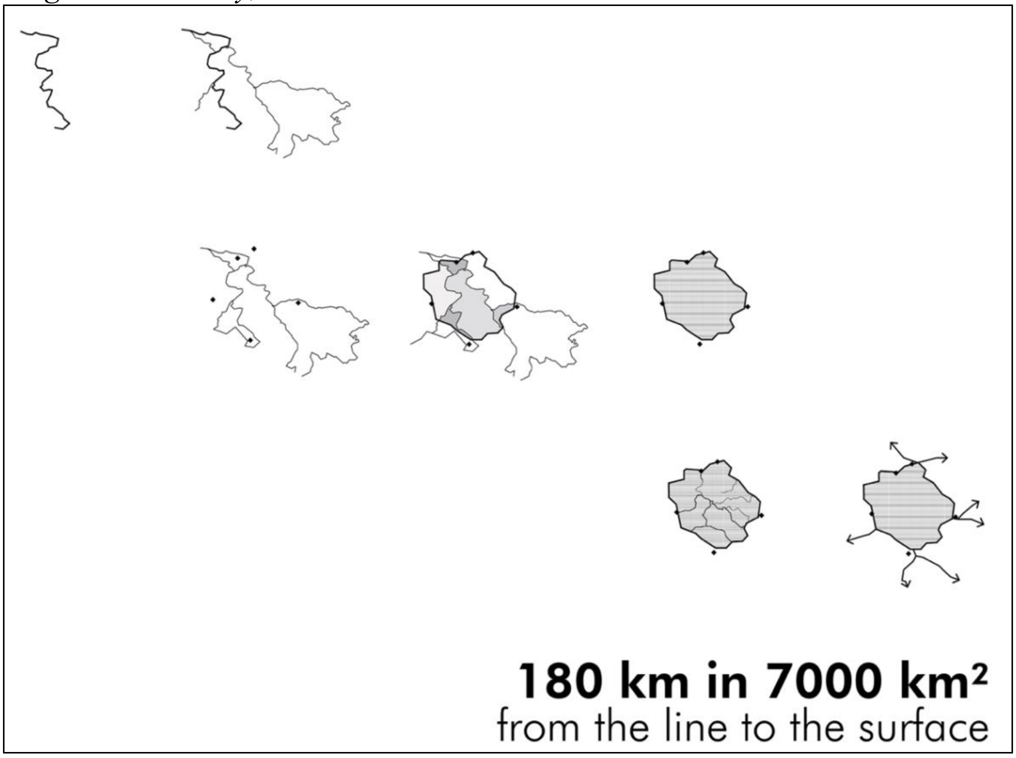
The research thesis finds that the capacity of geography does re-write and inform always new architectonic languages; vice versa architecture –if considered from the geographer's point of view– re-shapes periodically, through scales, history of geography and its very representation, always new relations, arrangements, original texts that are the result of territorial processes (Figures 5-6) (Albrecht and Benevolo 1992). That is, in Corboz's (1985) words, the codification of the palimpsest. The research had these main objectives:

[*]Researcher, University of Trieste, Italy.

- Elaborating a new interpretation of architecture and landscapes, shaped on the geographic matrix of the border, in the aforementioned cross-border region.
- Developing a cross-cutting dialogue on territorial models shaped on the edge between geography and architecture.
- Designing landscape and infrastructure project proposals for cross border areas within a cross border cooperation mindset.

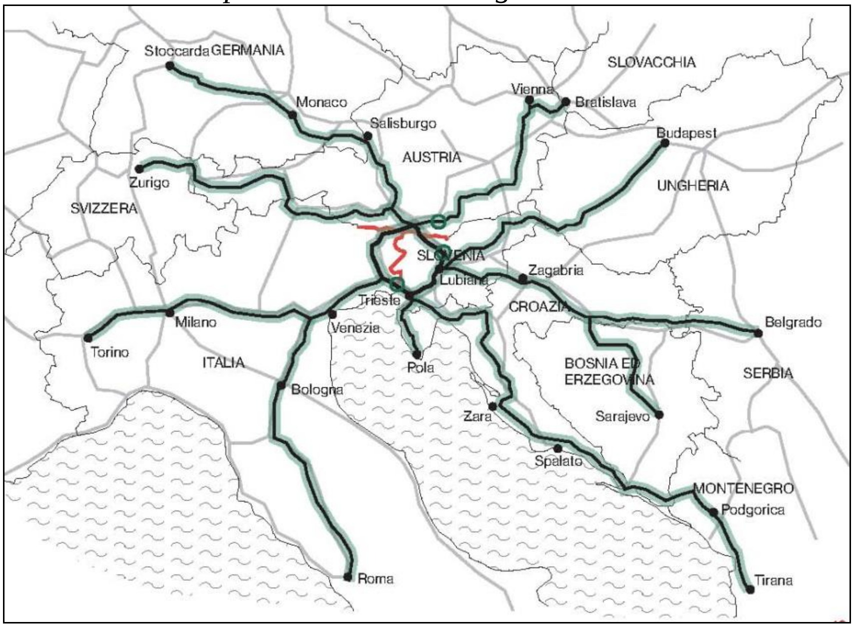
These objectives have made it possible to identify a new "territorial figure"; a new cross-border geography, the landscape-ring between Italy, Slovenia and Austria (Figures 2-4).

Figure 1. *Extension of the National Border at the Base of the New "Landscape-Ring" between Italy, Slovenia and Austria*



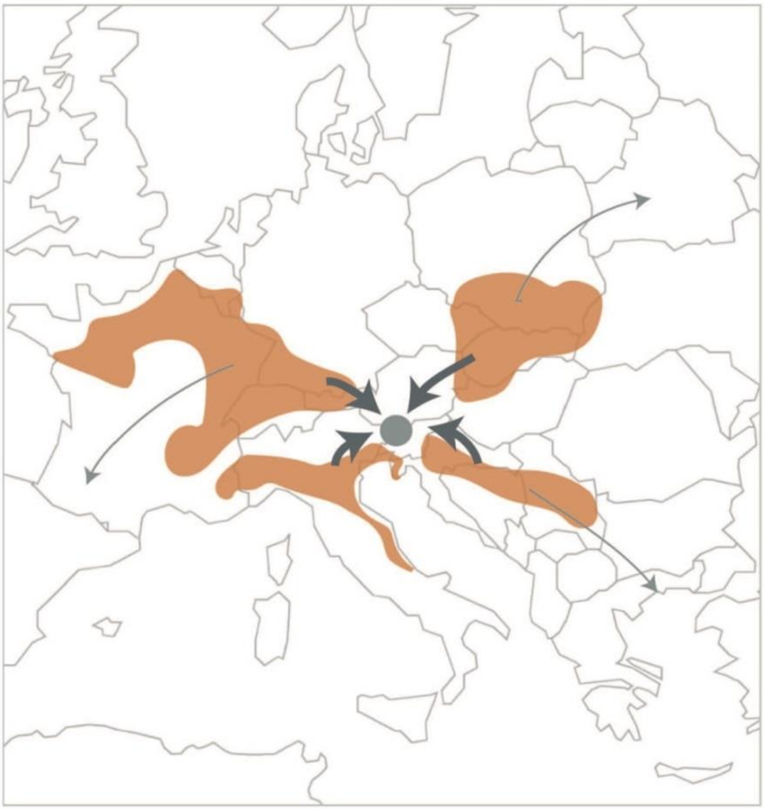
Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 2. *Recognition of the "Landscape-Ring", Contextualization and Territorial Insertion in the Alps-Adriatic Macro-Region*



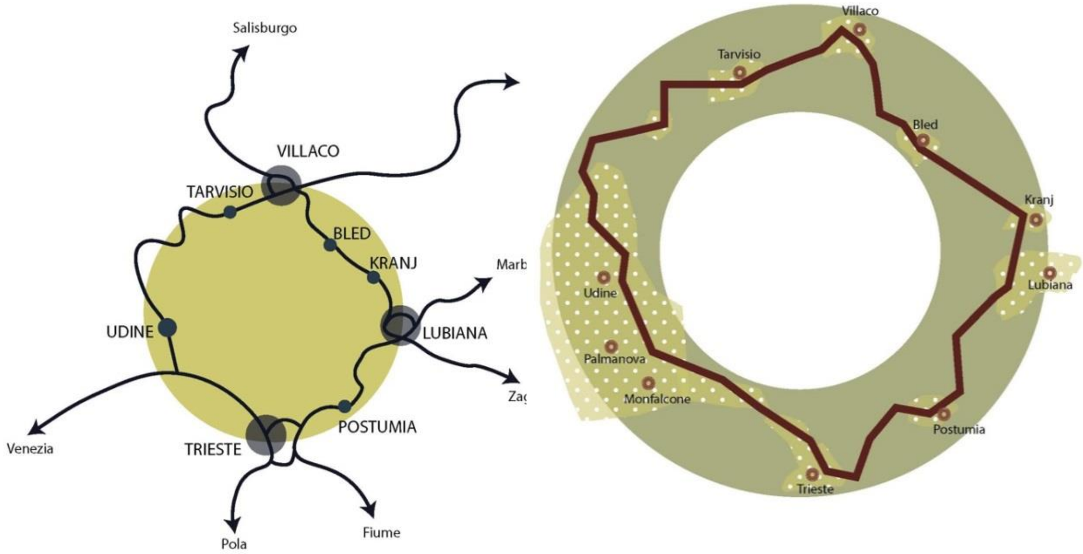
Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 3. *European Macro Region of Alpe-Adria and Localization of New "Landscape-Ring" between Italy, Slovenia and Austria*



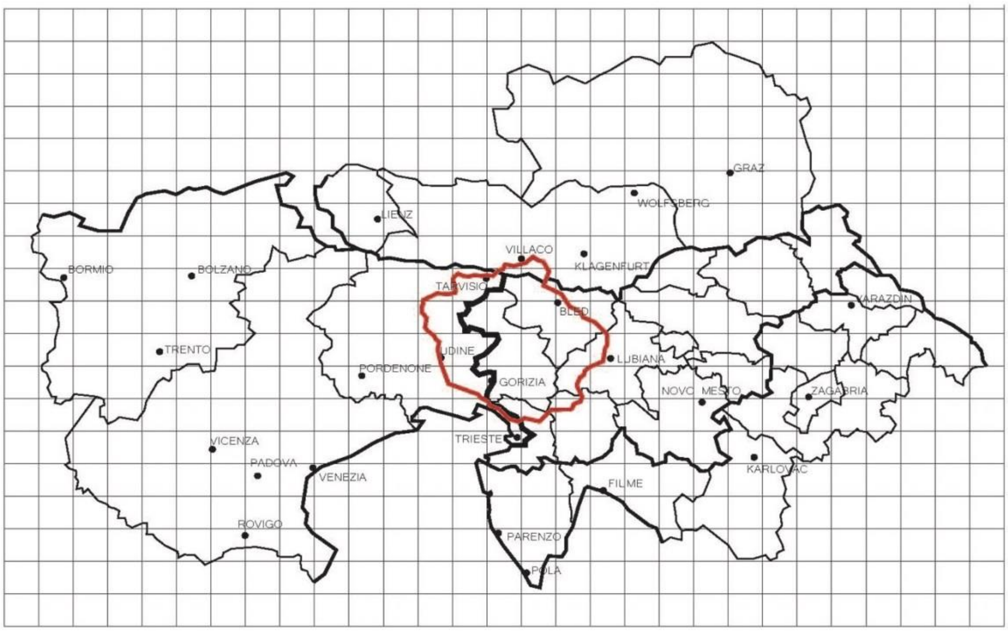
Source: Elaboration by Giulia Piacente, Stela Guni, Vittoria Umani.

Figure 4. *"Landscape-Ring" between Italy, Slovenia and Austria*



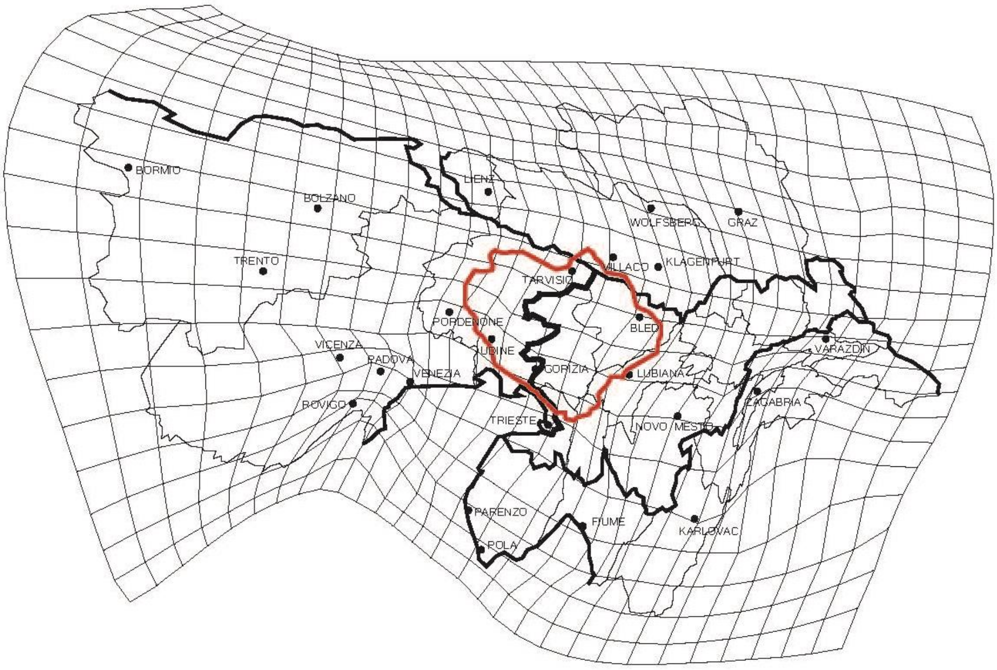
Source: Elaboration by Giulia Piacente, Stela Guni, Vittoria Umani.

Figure 5. *Space-Time Map of the Macro-Region before and after the Operation of the "Landscape-Ring"*



Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 6. *Space-Time Map of the Macro-Region before and after the Operation of the "Landscape-Ring"*



Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

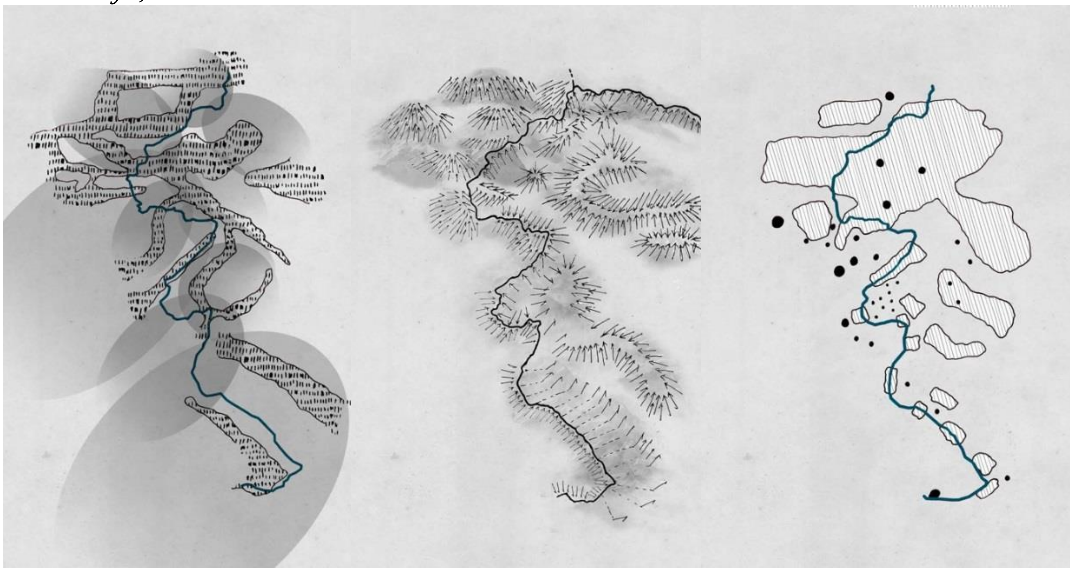
The border at stake, for known historical reasons (Bufon 1990) and, more recently, due to geo-morphological changes (i.e., it runs along the alpine region, where high altitude glaciers are currently shrinking due to climate change and fastly re-shaping the morphology of the land), is defined as a “moving” border. The alpine area moves along the movement of the glaciers (Figures 7-9), and so does the border, thus yearly modifying, even so slightly (Ferrari et al. 2018), the official geo-political maps (Figures 10-12).

To address this issue, the States along the Alpine chain (including Austria, Slovenia and Italy) have thus officially codified the concept of “moving border” (Biondi 1995), and that of “instability of geological elements”, traditionally considered unchanging. This leads to the scientific acknowledgement of the instability of natural borders, one of the pillars at the base of the concept of national territory. So, will climate change reshape, beside landscape structure, also the identity of these areas (Basso 2010)?

We have used the concept of "border as landscape" elaborated by Basso (2010) which has become a key to identifying the geographical areas of this cross-border region, and we structured the research in four steps, through survey and project tools, words and media for geographic elaboration, looking for the subtle connection between word and content, mapping and structure, territory and environment, landscape and place, shape and image.

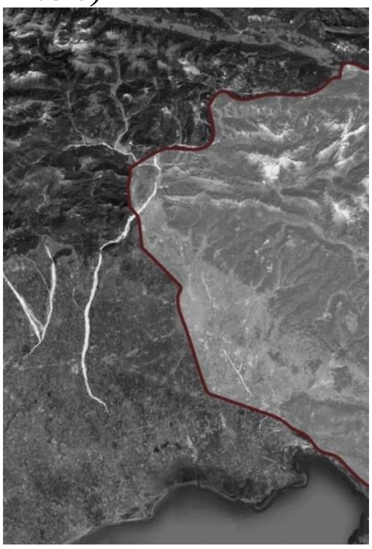
The studies of the 11 working groups were all put together to shape the new landscape’s mosaic. Eleven visions were developed, each imagining a new geography of the border. Together, they re-designed a new morphology of the *limes* (Figures 7-11), palimpsest of a multiethnic community where the remains of the history of places can write a new story between geography, landscape and architecture. These eleven visions in turn become the project making material for the overall re-shaping of landscape. The geographer Giorgio Valussi, between the end of 1950s and mid 1965s, conducted a series of studies on Carsic landscapes (Vallussi 1963), both in Italy and Slovenia, leading him to formulate the theory of the "geography of the border", finding its roots in the continuous changes within landscapes (Bufon 1994).

Figures 7-9. *Mobile Border Processing Diagrams*: *The Boundary in relation to the Valleys, Mountains and Glaciers*



Source: Elaboration by Angela Bertoni, Lorenzo Kratter, Giada Lesizza.

Figure 10. *Satellite Image of the Border between Italy, Slovenia and Austria (Regions of Friuli Venezia Giulia, Carinzia, Goriška, Gorenjsk and Obalno Kraska)*

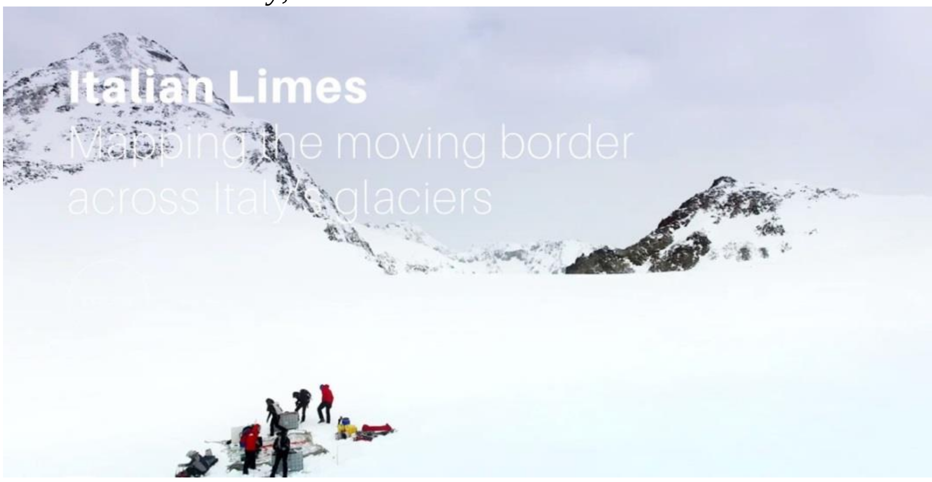


Source: Elaboration by Giulia Piacente, Stela Guni, Vittoria Umani.

Figure 11. *Morphology of Limes: The Environmental, Infrastructural and Settlement Systems of the Border Region*

Source: Elaboration by Angela Bertoni, Lorenzo Kratter, Giada Lesizza.

Figure 12. *Team of Researchers that Map the Movements of the Border on the Glaciers between Italy, Slovenia and Austria*



Source: www.italianlimes.net.

Tools and Methodology

From Immago Limes, to New Geographies

The research work was organized into four macro phases, which developed from analysis and data collection, to the development of synthesis and interpretation models, to arrive at the first indications of the masterplan:

The first phase, *immago limes* (Figure 14), implied an analytical reconstruction of the territory's structure, functioning, through the analysis of landscapes, systems (nature, settlements, infrastructures, etc.), fluxes, relations, historical evolution, current ongoing dynamics, obstacles/potential, through data gathering.

During the second phase, *visions*, data were interpreted, summary models were elaborated, extended areas were identified for each segment of the border line, indicators were chosen, ecologies were defined, and thematisation was carried out through "narration".

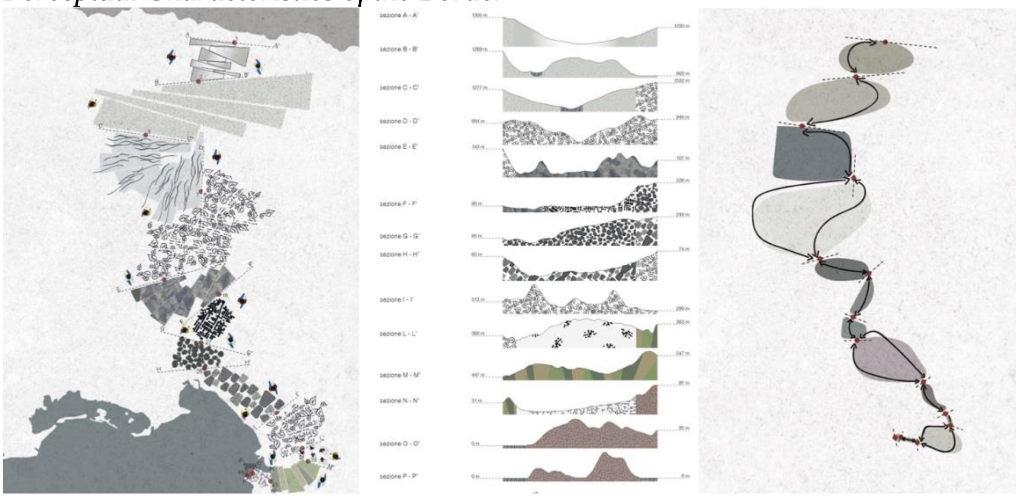
The third phase, *frammenti (fragments)*, implied the development of meta-projects concerning the overall thematisation and the identified obstacles/potential (Figure 13). These meta projects allowed for the focus on specific themes and places for the actual project.

During the fourth and last phase, *geographies*, all information, analytic and project elaborations and experiences were put together (Figures 15-16) to elaborate the final deliverables: eleven ecologies, maps of change, border landscapes, the cross border ring, the city of the border and the new geography of the border.

Figure 13. *Image of the Italy and Slovenia Border on the Trieste Karst*

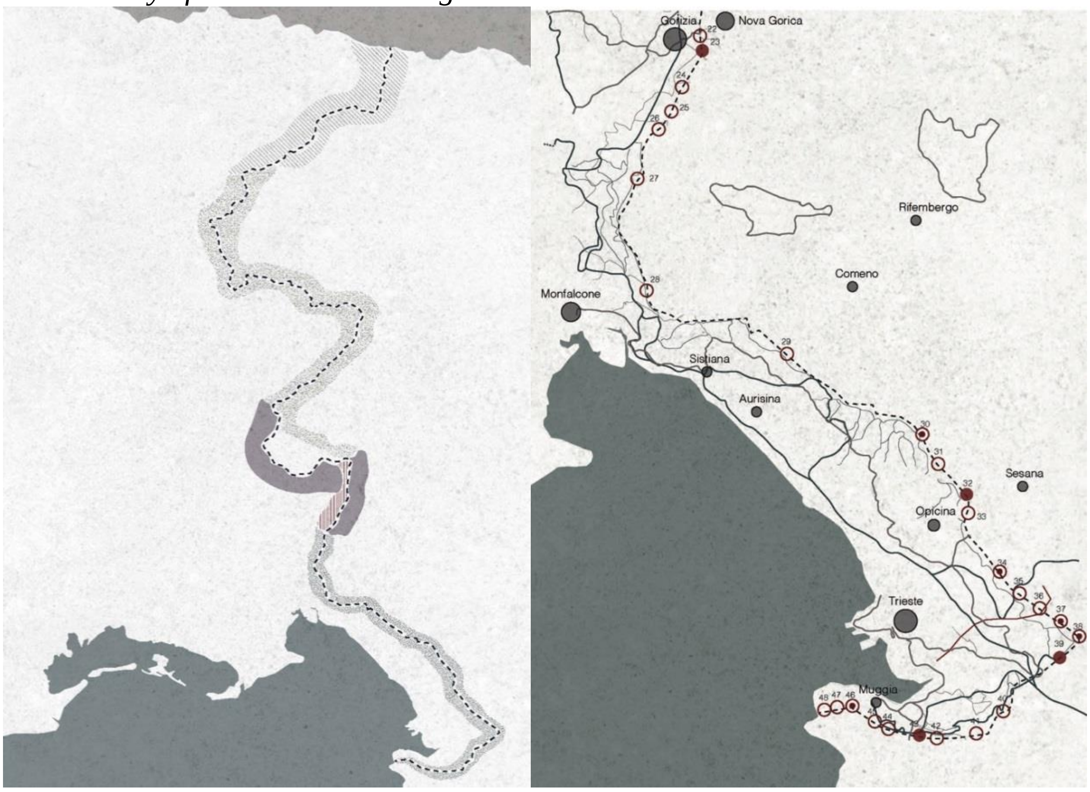
Source: Elaboration by Sofia Artico, Federica Ferrigno, Lara Slavec.

Figure 14. *Immago Limes: Interpretation of the Structural Components and Perceptual Characteristics of the Border*



Source: Elaboration by Giorgio Conforto, Eleonora Di Stefano, Debora Paulin.

Figures 15-16. *Pre-Geography of the Border Redesigned on the Basis of the Permeability of the Border-Crossings*



Source: Elaboration by Giorgio Conforto, Eleonora Di Stefano, Debora Paulin.

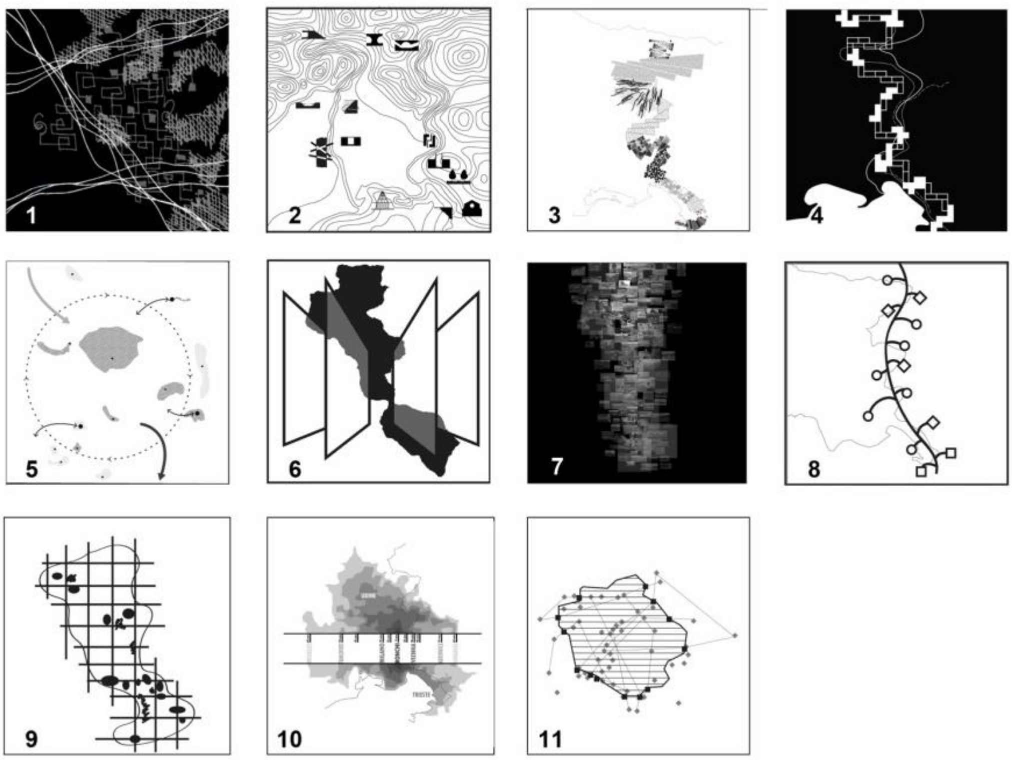
Discussion

Mapping the Change

The structure of the territory, the stratification of the landscape and the measurement of social and economic transformations are the basis of the proposal for this "new geography of the border". A series of thematic maps have been developed which consider all these areas of investigation as indicators of the structural value of the "mobile border". The result obtained is a set of representations, with a visual approach to human geography (Greiner et al. 2012), which are the index of the relationship between territorial systems and dynamics of functioning (linked precisely to the border). In order to map the ecologies of communities (Dematteis 1991), eleven characters were chosen to represent the layering of the territory and of its landscapes, and their perspectives were used for mapping changes, as key indicators of the complex ongoing transformations, especially with respect to the ethnic mosaic, the true origin of this complexity, concept theorized by La Cecla in "What are borders for?" (La Cecla 1996). From this book by La Cecla the idea was born to visualize "the geography of the characters" of the border and to edit anthropogeographic maps, which could represent the ecologies of change. These characters are: Inhabitant; The poet; The onlooker; The artist; The commuter; The unemployed; The priest; The collector; The miner; The traveler; The pilgrim.

The representation of the ecologies of change (Dematteis and Ferlaino 2003) is embodied in eleven cartographies that together show the moving dimension of the border space (Figure 17). These are: 1. Map of resonance; 2. Map of poetic actions; 3. Map of landscapes; 4. Map of intersections; 5. Map of the arcipelago; 6. Map of stratigraphy; 7. Map of memories; 8. Map of paths; 9 Map of diagenesis; 10. Map of fluxes; 11. Map of exceptions.

Figure 17. *Ecologies of Change Map. The Summary Maps of the 11 Ecologies of Change are: 1. Map of Resonance (Lorenzo Kratter, Giada Lesizza, Angela Bertoni); 2. Map of Poetic Actions (Virgini Fabbro, Silvia Musini, Arianna Santarsiero); 3. Map of Landscapes (Giorgio Conforto, Eleonora Di Stefano, Debora Paulin); 4. Map of Intersections (Sofia Artico, Federica Ferrigno, Lara Slavec); 5. Map of the Archipelago (Stela Guni, Giulia Piacente, Giulia Toscano, Vittoria Umani); 6. Map of Stratigraphy (Vlad Maricel Martinas, Semir Skenderovic); 7. Map of Memories (Ivan Bello Ivan, Jesku Franklind); 8. Map of paths (Giacomo Caporale); 9 Map of Diagenesis (Lorna Mattias, Michela Contin, Devescovi Valentina); 10. Map of Fluxes (Matteo Ros, Milisav Stankovic, Enrico Vidulich); 11. Map of Exceptions (Matteo Savron, Elwira Wojcicka, Monica Bidoli)*



This constant change of the territory, that could apparently seem an issue for territorial identity, represents indeed an element of unity (physical, morphologic, economic) of landscape and territory, etc.) and the main character of the identity of the cross-border region (Zanini 1997).This is indeed the reason behind the attempt to elaborate a "new own geography", based on the paradigm of mutation itself (Dematteis 1996).

Starting from the shape of the cross-border ring, different themes were investigated:

1. Dimension, perception, stratifications.
2. Re-reading, narrations and landscapes, literature and poetry of the territory.
3. Landscape unity, natural macrosystems, environment, vegetational structures, panoramic views.
4. Art and nature.
5. Systems, infrastructures, territorial settlements, heritage system.
6. Abandonment.
7. Memory and territorial symbology.
8. Backbone and infrastructure.
9. Morphology, lithology and extraction plants.
10. European corridors and regional networks.
11. Slow landscapes, paths, places of worship.

The analytical reading was elaborated with two visions in mind:

1. A taxonomy chart of landscapes (sound, imagination, perception, art, mankind, habits, industrial archeology, memory, movement, earth, speed, spirituality).
2. A new "map" allowing for a new interpretation of the border extended area as a whole territory, with its own geography.

The eleven visions elaborated (thematisms) codify the layers of the cross-border landscape, with the aim to develop:

1. Tools allowing for the interpretation of the ongoing change.
2. A "pre-geography of the border", aimed at orienting the urban and landscape planning within the cross border cooperation framework among Italy, Slovenia and Austria.

Hypothesis

A New Landscape-Ring between Italy, Slovenia and Austria

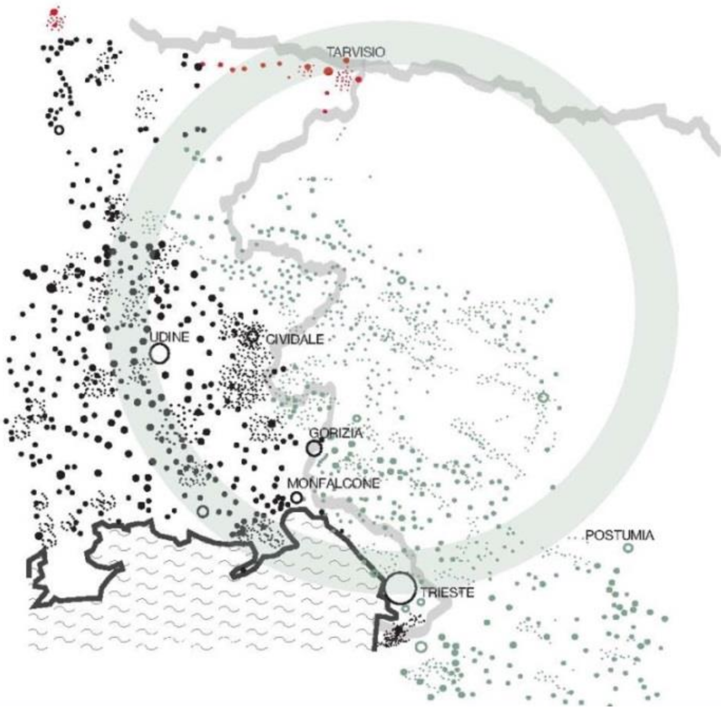
The experimentation of new tools and methodologies for the study of the landscape geography's was a further objective, correlated to the main one of this research (study of the landscape-ring). The experimentation also concerned the methods of data collection and the use of the appropriate tools, languages, and finally the construction of the narrative/description (geographic). The expected results aimed at defining a new geography of the border, the results obtained stopped a little earlier, then between a geography and a pre-geography. Pre-geography is a figure born out of uncoded and unstable systems. Precisely by means of this informal condition, the approach to pre-geography manages to bring out often illegible structures and systems. Constellations are the most significant example of what could be a "pre-geography".

In the end it was decided to maintain an incomplete, pre-geographic layout for the open, generative character, as if they were a guideline, because they will probably be more useful and effective than a configuration concluded or closed for programming, mediation and cross-border cooperation activities.

The case study dealt with an area that stretches along the border of three states, five regions, involving numerous landscapes from the mountains to the sea. Eventually, putting together the eleven visions elaborated by the working groups, an extended area of about 7000 mk^2 was identified as the actual "region of the border" (Figures 18-19), in particular infrastructure and landscape. This regions lays within a bigger cross-border ring whose shape is defined by pieces of existing infrastructures, already identified as territorial frame in the studies of Luciano Di Sopra on the Friulian urban structure (Di Sopra 1967), belonging to other systems, but representing, within the ring around the border, a new important infrastructure serving the territory. It also represents a functional unity, an autonomous system, a whole structural unity for the region of the border. The infrastructures used for this new re-shaping of the functionalities of the territory are highways A4 and A23 in Italy, freeway E61 and E652 in Slovenia and highways A2 in Austria (Figures 20-23). This ring will allow to build new internal and above all external territorial relationships, in particular with the whole of central Europe (Figures 21-22). It exploits an existing condition (Figures 23-25) to encourage mobility and more widespread connections for the whole "border region". We have recognized numerous territorial systems within this ring, which are configured as constellations (Figure 25), which give strength and unity to a sort of "new border region".

Now if we reinterpret this "border territory" according to this ring structure, we will be able to identify an original constellation of landscapes (Figure 25), natural systems, small villages, linear settlements and cities. What before appeared to us as a local fragmentation and banal settlement dispersion, by means of our landscape-ring (new interpretation) now takes on a local, national, transnational configuration: a huge "city-border". It is an infrastructure that already exists, and that already partially functions as an "infrastructure-ring" around the border. Now few resources would be needed to make it function as a cross-border territorial system. Later, according to a time schedule, it can also be used as a starting point for cross-border urban, landscape and territorial development (Figure 24).

Figure 18. *Thematic Map of the Border Region "Discovered" within the Landscape-Ring. The "Sprawltown of the Border" is Extended within a Kind of Large Ring that Crosses the Border between Italy, Slovenia and Austria*

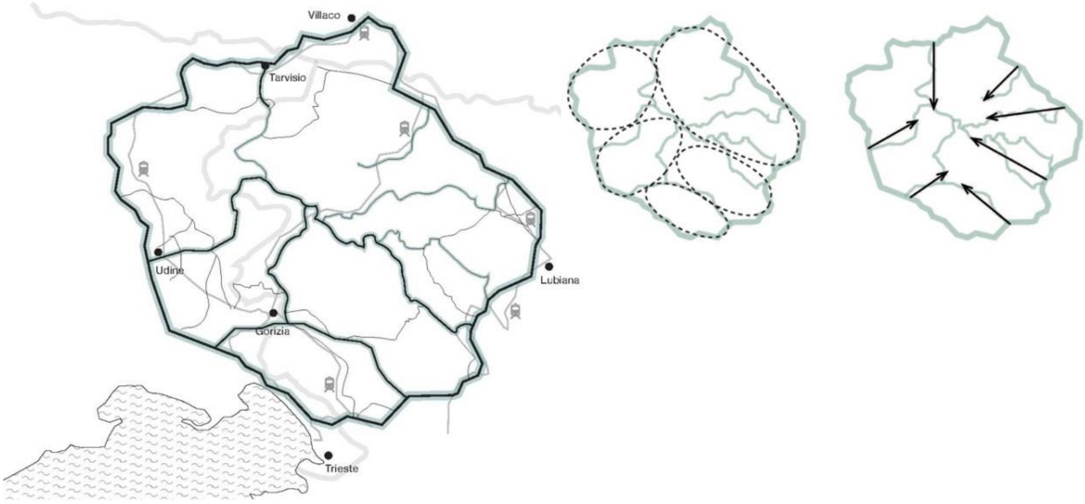


Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 19. *Panoptic Diagram Showing the Edges and Landscapes of the Landscape-Ring from the Road*

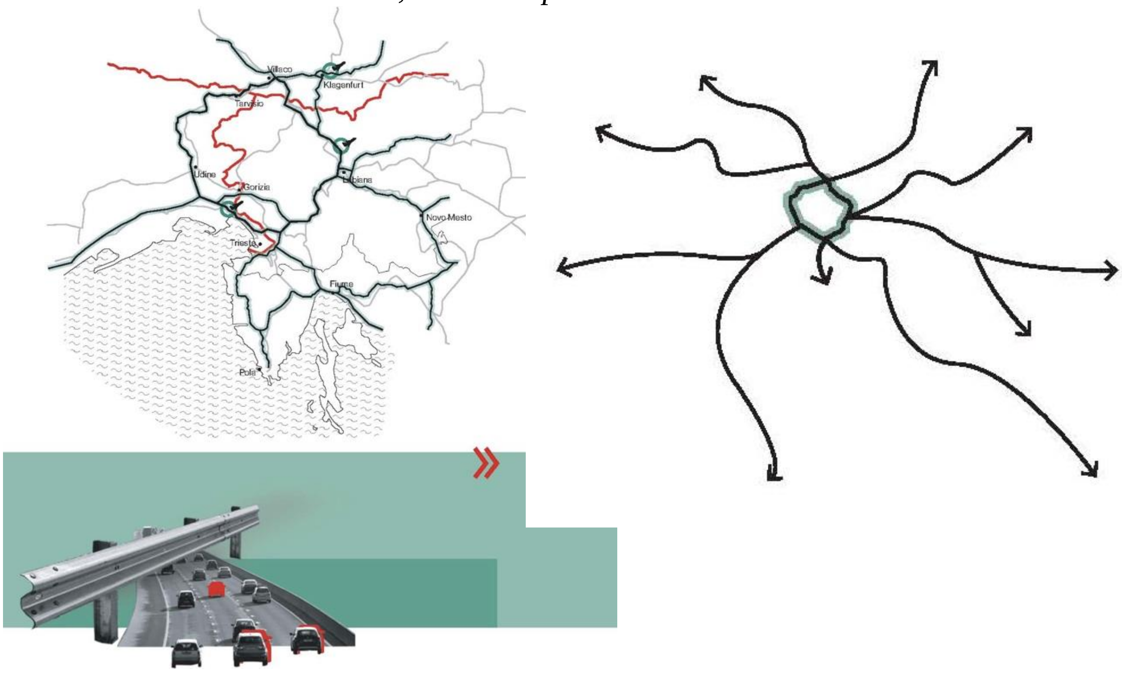
Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 20. *Maps Showing the Infrastructures Used for this New Re-Shaping of the Internal Functionalities of the Territory: Highways A4 and A23 in Italy, Freeway E61 and E652 in Slovenia and Highways A2 in Austria*



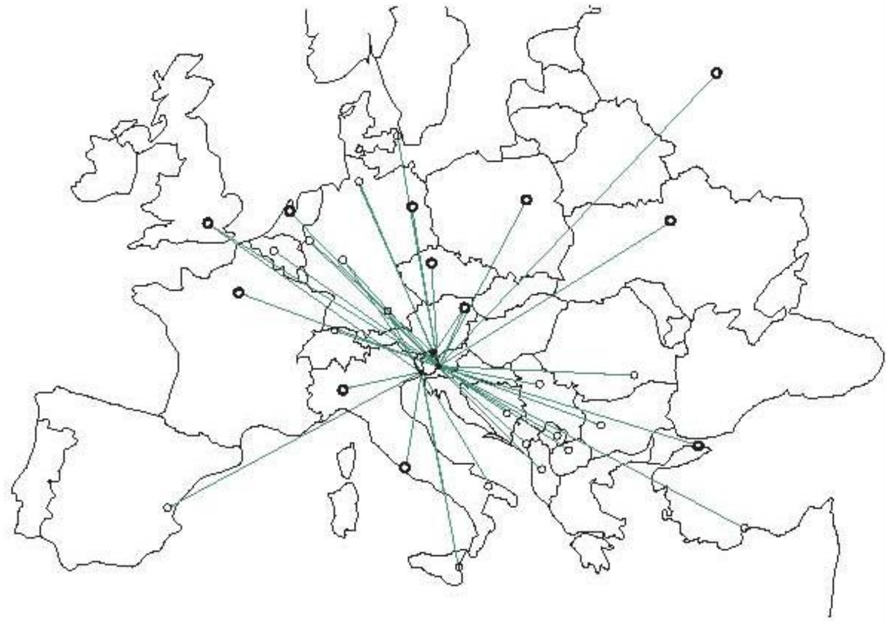
Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 21. *Maps Showing the Infrastructures Used for this New Re-Shaping of the External Functionalities of the Territory: New Relations of the Border Region with the Nearest External Territories, Mitteleuropa*



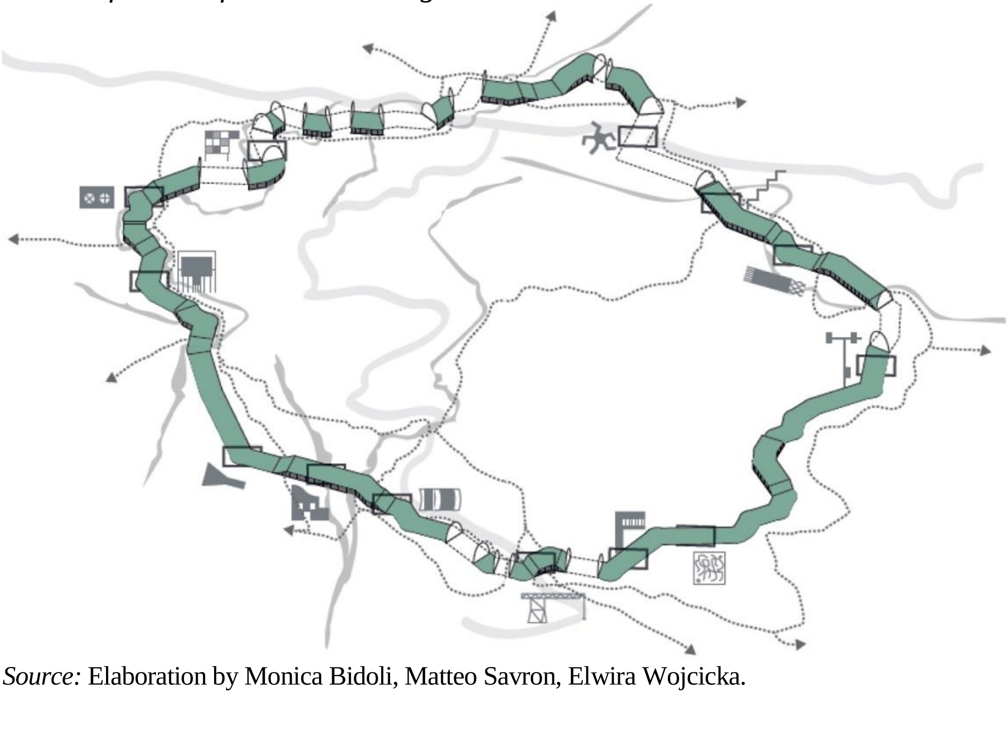
Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 22. *Maps Showing the Potential Connections between Landscape-Rin with Central Europe. This Territorial Infrastructure and New Relationships Reshape the Geography of the Border, but also of the Region on which it is Located*



Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 23. *Punctual and Linear Interventions for the Completion of the Ring and the Redefinition of the Internal Region: New Cross-Border Territories*

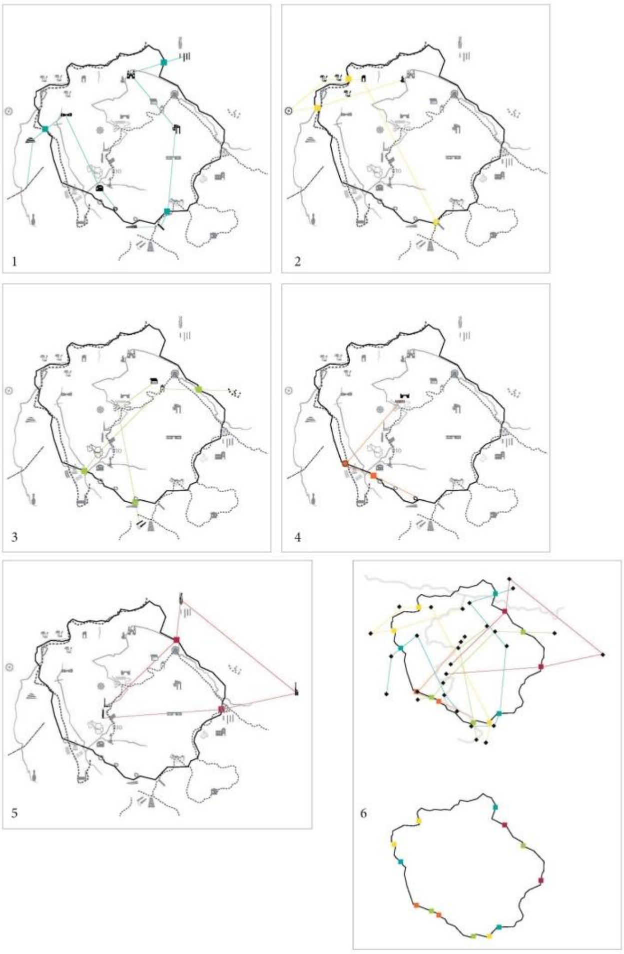


Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 24. *Synthesis of the Systems that Make up the Landscape-Ring: Infrastructure Ring, Settled Housing Areas, Naturalistic Areas, Architectural and Cultural Emergencies*

Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

Figure 25. *Systems Levels and Constellations of the Landscape-Ring and the Internal Border Region: 1 Relevant Sites; 2 Places of Memory; 3 Rare Public Services; 4 Flow and Mobility Services; 5 Centers of Interest; 6 Overall Constellation*



Source: Elaboration by Monica Bidoli, Matteo Savron, Elwira Wojcicka.

A New "European-Figure": European Green Belt

Studies and research conducted by various German Universities and the European "GreenNet" project within the "European Green Belt" program have discovered the existence of a new continental geographical system, between 2011 and 2013: the *European Green Belt* (Figure 26). It is a macrosystem of nature, of continental extension that develops along what was the border of the "iron curtain", and which was formed following the imposition of this border after the Second World War (Figure 27). This border, so hard and artificial, has kept away the phenomena of anthropization and waterproofing of soils and above all its buffer zone, has generally preserved incredible levels of naturalness (Figures 28-29). It is paradoxical that the defense, closure and blocking wall has become over the years a system of continuity, a very important vector of naturalness and an ecological system on a European scale. This border line (the "iron curtain") has been an obstacle and a problem for more than 40 years, but today it is a resource on which the whole of Europe can review the management and organization of its environmental macro-systems according to a new naturalistic constellation, which will be able to redesign the entire continental geography. Our case study concerns a part of this European Green Belt and our research project (landscape-ring) fits into this new European geography (Figure 28).

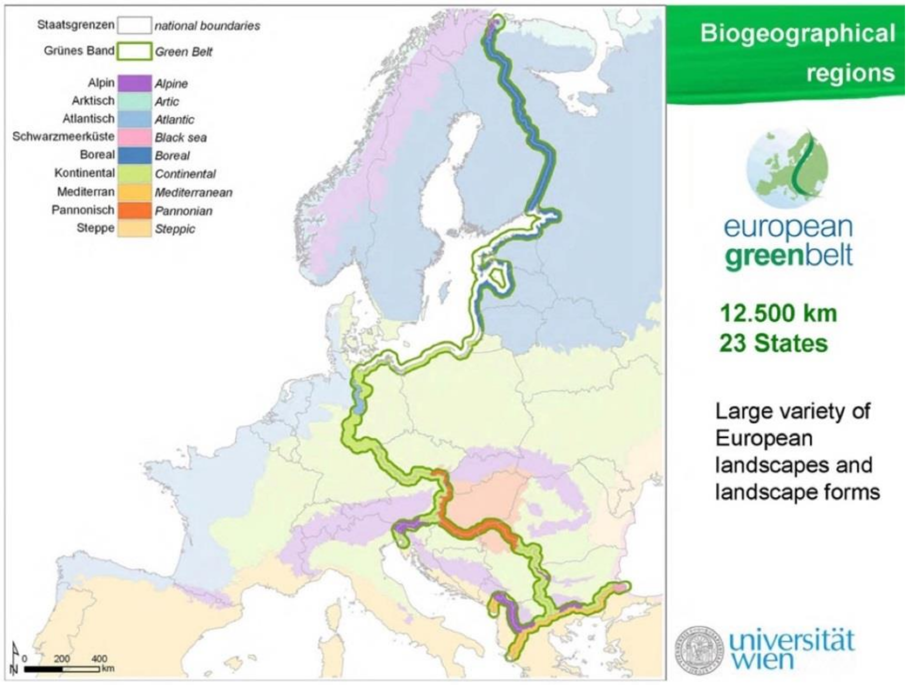
Figure 26. *European Green Belt along the Border "Cortina di Ferro"*

Source: Book of GreeNet – 1st Scientific Conference. The Green Belt as a European Ecological Network, 2012.

Figure 27. *European Green Belt along the Border "Cortina di Ferro": Border Images before 1986*

Source: Book of GreeNet – 1st Scientific Conference. The Green Belt as a European Ecological Network, 2012.

Figure 28. *European Green Belt along the Border "Cortina di Ferro": Environmental Identifications and Sites of Naturalistic Interest*



Source: Book of GreeNet – 1st Scientific Conference. The Green Belt as a European Ecological Network, 2012.

Figure 29. *European Green Belt along the Border "Cortina di Ferro": High Biodiversity Nature Reserves along the Border*

Source: Book of GreeNet – 1st Scientific Conference. The Green Belt as a European Ecological Network, 2012.

Environmental Continuity and Landscape Unity: A Cross Border Region

In the last two centuries the region was subject to great transformations, from the administrative and political point of view. These changes have left their traces on the physical appearance of the territory as well as on the communities that inhabit it. Multiethnicity has always represented the base for the mixing of cultures and local identities. The main reason behind the dynamic balance between unity and fragmentation (Figure 30) within this region is the high level of permeability of this border, defined also as an "open border" (Valussi 1974). The paradigm of change lives within the very genetic heritage of this territory, both from the physical/morphologic and from the anthropological/cultural perspectives.

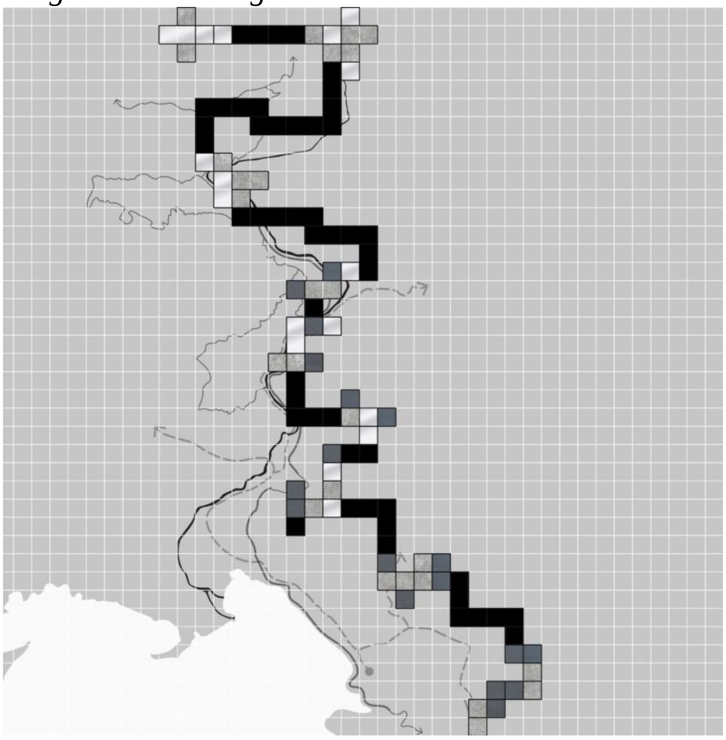
Currently three national States (Italy, Slovenia and Austria) share this border, but the region itself is a whole macro-region, unified by history, culture and geo-morphology. Territorial systems overlap and shape different geographies, thus filling in the space of the border according to the "cross-border concept" (Gabrijelčič 2004) or to the idea of "transational cell" (Hudnik 2004).

The study area runs across the border regions of Friuli Venezia Giulia in Italy, Carinthia in Austria and Goriška, Gorenjsk and Obalno Kraska in Slovenia. This area has, throughout history, always been a passage towards the East. The territory has always been divided among different national States, but can be considered as a whole for what concerns its "common matrix", rooted in its identity of a cross border region (Jeršič 1970).

The natural systems of the territory at stake (Sistema Carta Natura, ISPRA) have a strong ecological and landscape unity (woods and forests, rivers, lakes, mountain ranges, glaciers, valleys, coast). The many small towns and five bigger centers (Tarvisio, Gorizia, Trieste, Lubljiana, Villach) located in this area, for historical reasons (such as re-definition of the borders between States after the II World War) found themselves without a real territory beside the fragmented one represented by the cross border. The geographic position as gate towards the East has favored, throughout the centuries, the creation of important transport infrastructures and of the European corridors. This allowed for a direct connection with central Europe, for what concerns trade and commerce. Thus, this "informal region", geographically located in a peripheral position, was included in a continental exchange loop, despite not being officially recognized as a whole unit from the political, administrative and economic point of view.

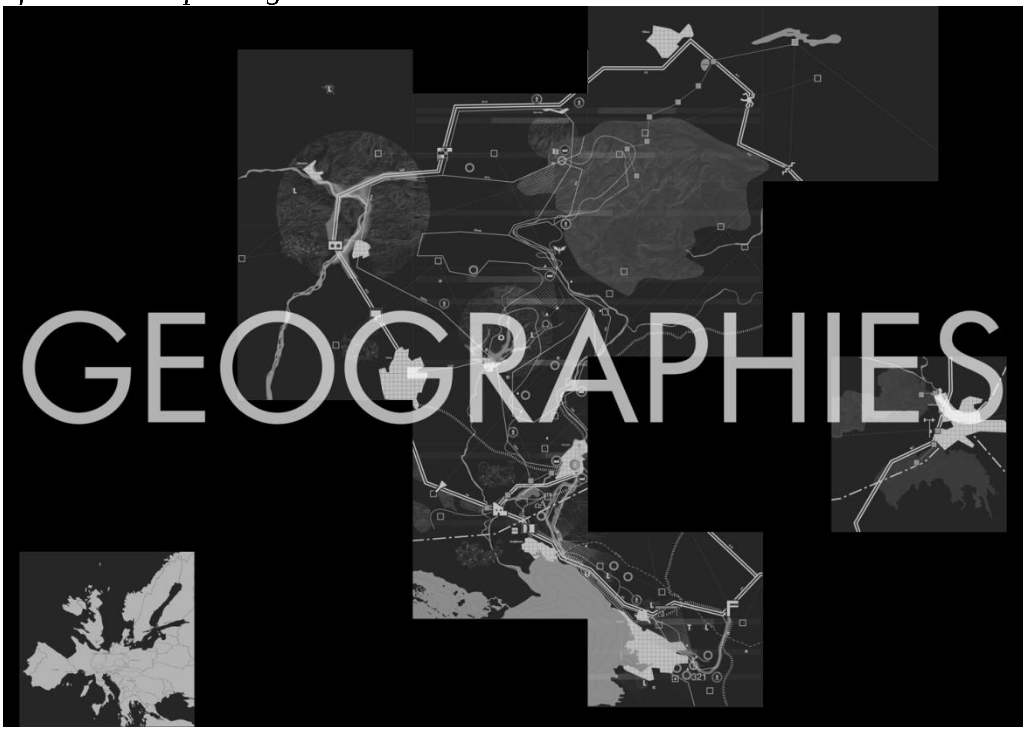
It seems thus relevant to point out that the fragmentation and constant change that the border has always generated in this area has paradoxically given birth to a unitary territorial entity (Figure 31), that was also partially formalized, in the last 25-30 years, as Euroregion, Alpe-Adria, Macroregion, etc., for economic, political administrative, environmental, managerial, social, landscape purposes.

Figure 30. *Original Territorial Structure of Departure: The Border Analysis of Fragmentation along the Border*



Source: Elaboration by Sofia Artico, Federica Ferrigno, Lara Slavec.

Figure 31. *New Geography Map of the Border Region Following the Re-Shaping of the Landscape-Ring*



Source: Elaboration by Lorenzo Kratter, Giada Lesizza, Angela Bertoni, Virgini Fabbro, Silvia Musini, Arianna Santarsiero, Giorgio Conforto, Eleonora Di Stefano, Debora Paulin, Sofia Artico, Federica Ferrigno, Lara Slavec, Stela Guni, Giulia Piacente, Giulia Toscano, Vittoria Umani, Vlad Maricel Martinas, Semir Skenderovic, Ivan Bello Ivan, Jesku Franklind, Giacomo Caporale, Lorna Mattias, Michela Contin, Devescovi Valentina, Matteo Ros, Milisav Stankovic, Enrico Vidulich, Matteo Savron, Elwira Wojcicka Monica.

Results and Conclusions

Landscape Shapes and Geography Figures

As Corboz (1985) wrote the territory is not a given, but is always the result of many processes: “The constant mutation originates from reasons related to geology and meteorology, therefore to nature, and from reasons related to voluntary human activities” (Corboz 1985). Corboz also maintains that the inhabitants of a territory constantly erase and rewrite the ground. The continuous rewritings with geoclimatic mutations contribute together to commute the territory as an artifact, as a product. An “unfinished product”, in which however, the very bond of the inhabitants is established on the possibility / necessity of transformation of reprogramming. For these reasons the territory is a project (Corboz 1985).

These topics are even more evident in the territories when the same geographical area is disputed between different ethnic groups, which elaborate different projects for the territory. The dynamism of the "territory phenomenon" is so evident when belonging to a topographical area is experienced as a collective experience, and therefore falls within the "imaginary of the territory".

If we use a geographical and anthropological approach together to re-read this border region, the border-landscape and the border-territory contrasts are mitigated, because the concept of limes as space prevails (Basso 2010). The very idea of boundary as space is no longer that generated by the paradigm of division, but of continuity. A continuity of landscapes and architectures that follow one another in oriented sequences along the 180km of this mobile line, and around which all the inhabitants (Slovenians, Italians and Austrians) have acquired a cross-border mentality regardless of their nationality. An important question emerges from the analyses: territory-border coincidence. So if our case study is a mobile border, the territory identified with it also constantly changes the geography of this cross-border region (Figure 31).

The project-making approach towards the elaboration of a masterplan aimed at valorizing the diversities within the territory, that have always shaped the ways of life (Greiner et al. 2012) and of inhabiting (Kačič et al. 2001), the settling principles at the roots of cross border cities and villages, the ways of cultivating and managing landscape, the creation of an architectonic jargon of the border (Zanirato 1999). The masterplan investigates forms and "shapes of diversity" that are capable of enhancing unity and sense of belonging to a whole territory. The history of the city and of the territory (Benevolo 1993) remind us that great infrastructures, such as the roman aqueducts (Figure 32), the consular roads, the defensive structures of the Chinese Great (Figure 34), Wall or Hadrian's Wall (Figure 33), the pilgrimage routes (Figure 36), and more recently the European corridors have always contributed to shaping unity.

History suggests also other means for building unity (Benevolo 1993), for instance through the symbolic or functional construction, for example of bell towers (Figure 35), or landmarks, water's towers, or the development of a "unitary vision" through great landscape and perspective, rearrangements, so as theorized by Benevolo (1991) in "Capture of infinity". The shaping of the territory, especially in the Mittel-European area, has been understood and developed as management of change (Klemenčič 1979) and historically was always embodied by landscape architecture (Benevolo 1991), while finding its actual effectiveness only when codified by geography systems (Dematteis 1996).

Figure 32. *Roman Aqueduct (I sec. d.c.)*

Figure 33. *Hadrian's Wall (II sec. d.c.)*

Figure 34. *Great Wall of China (II sec. a.c.)*

Figure 35. *Series of Historical Bell Towers in the Study Area: Landscape Landmarks and Community Identity*

Figure 36. *Monte Berico, Vicenza. Pilgrimage Route (1700)*

The “Itineraria Picta”, the "Peuntiger Table"(Figure 37), the commercial maps of the territory of the Venetian Republic of Guadagnino, the great topographical campaigns of the Austro-Hungarian Empire or even the most recent ones of the Italian Geographical Military Institute are among the most significant examples of this semantic connection between geography, history and landscape. The role of narration in representation has always been decisive for the construction of the meaning of places (genius loci), just think of the maps and tourist guides developed by the Italian Touring Club that have strongly contributed to the creation of a culture and awareness of the landscapes.

Finally, it is worth also mentioning as an example the recent maps of the “future world order”, related to communication, new media and energy (Khanna 2016).

A constant evolution of forms of the geographical space has taken place parallel to human evolution as described by Ghosn and Jazairy (2018) and to the evolution of tools and methods (Dinic 1976).

Figure 37. *Peutigerian Table of Istria (XII-XIII sec.)*

Acknowledgments

Our thanks to: Research and didactic unit: Integrated Design and Architecture Laboratory, Department of Engineering and Architecture, University of Trieste (IT) with Faculty of Architecture of Ljubljana (SLO), Year: 2018-2019.

Coordinator and scientific manager: Giovanni Fraziano (DIA – UNITS). Team of researchers: Adriano Venudo, Thomas Bisiani, Claudio Meninno, Luigi Di Dato, Marko Verri, Stefano Simionato (DIA -UNITS), Špela Hudnik (Faculty of Architecture, University of Ljubljana). Students who have collaborated on the research team: Sofia Artico, Ivan Bello, Angela Bertoni, Monica Bidoli, Giacomo Caporale, Giorgio Conforto, Michela Contin, Valentina Devescovi, Eleonora Di Stefano, Virginia Fabbro, Federica Ferrigno, Jesku Franklind, Stela Guni, Lorenzo Kratter, Giada Lesizza, Vlad Maricel Martinas, Lorna Mattias, Silvia Musini, Matteo Ros, Debora Paulin, Giulia Piacente, Arianna Santarsiero, Matteo Savron, Semir Skenderovic, Lara Slavec, Milisav Stankovic, Giulia Toscano, Vittoria Umani, Enrico Vidulich, Elwira Wojcicka.

References

Albrecht B, Benevolo L (1992) Confini: un'ipotesi di lavoro. (Borders: a working hypothesis). In *Esposizione internazionale della XVII Triennale, La vita tra cose e natura: il progetto e la sfida ambientale*. Milan: Electa.

Basso S (2010) *Nel confine: riletture del territorio transfrontaliero Italo-Sloveno*. (In the border: reinterpretations of the Italian-Slovenian cross-border territory). Trieste: EUT.

Benevolo L (1991) *La cattura dell'infinito*. (The capture of infinity). Roma-Bari: Laterza.

Benevolo L (1993) *Storia della città. La città contemporanea*. (History of the city. The contemporary city). Roma-Bari: Editori Laterza.

Biondi N (1995) *Il confine mobile. Atlante storico dell'Alto Adriatico 1866-1992. Austria, Croazia, Italia, Slovenia*. (The mobile boundary. Historical Atlas of the Upper Adriatic 1866-1992. Austria, Croatia, Italy, Slovenia). Monfalcone: Edizioni della Laguna.

Bufon M (1990) *Sviluppo etnico e regionale delle aree di confine: il caso degli sloveni nel Friuli-Venezia Giulia*. (Ethnic and regional development of border areas: the case of Slovenians in Friuli-Venezia Giulia). Trieste: Slori.

Bufon M (1994) Per una geografia delle aree di confine. Il caso della regione transconfinaria italo slovena nel Goriziano. (For a geography of border areas. The case of the Italian-Slovenian cross-border region in the Gorizia). *Rivista Geografica Italiana* 101(4): 577–605.

Corboz A (1985) Il territorio come palinsesto. (The territory as a schedule). *Casabella* 516(Sep): 22–27.

Dematteis G (1991) *Le metafore della terra: la geografia umana tra mito e scienza*. (The metaphors of the earth: human geography between myth and science). Milan: Feltrinelli.

Dematteis G (1996) Immagini e interpretazioni del mutamento. (Images and interpretations of the change). In A Clementi, G Dematteis, PC Palermo (Eds), 66–79. *Le Forme del Territorio Italiano*. Bari: Laterza.

Dematteis G, Ferlaino F (Eds) (2003) *Il mondo e i luoghi: geografie delle identità e del cambiamento*. (The world and places: geographies of identities and change). Torino: Istituto di Ricerche economico-sociali del Piemonte.

Di Sopra L (1967) *La struttura urbanistica friulana. Analisi e pro*spettive. (The Friulian urban structure. Analysis and perspectives). Udine: Del Bianco Editore.

Dinic J (1976) *De la régionalisation de l'espace géographique de la Yugoslavie*. (The regionalization of the geographic space of Yugoslavia). *L'Espace Géographique* 5(1): 49–57.

Ferrari M, Pasqual E, Bagnato A (2018) *A moving border: Alpine cartographies of climate change*. Columbia Books on Architecture and the City.

Gabrijelčič P (2004) *Internationalisation of the border: the place of global iniziative. Development of border region in view of European integration efforts*. Retrieved from: www.borderlink-is.net/Newsletter01.html.

Ghosn R, Jazairy EH (2018) *Geostories: another architecture for the environment*. Barcelona: Actar.

Greiner AL, Dematteis G, Lanza C (2012) *Geografia umana: un approccio visuale*. (Human geography: a visual approach). Torino: UTET Università.

Hudnik S (2004) *Europe=City without borders*. Retrieved from: www.borderlink-is.net/Newsletter01.html.

Jeršič M (1970) *Odprtost mei kot dajavnik v razvoju Slovenskih obmejnih regij - L'apertura dei confini come fattore di sviluppo delle regioni confinarie Slovene.* (Openness as a factor in the development of Slovenian border regions - The opening of borders as a development factor for Slovenian border regions). Ljubljana: Inšt. Za geografico Univerze Ljubljana.

Kačič R, Scherl F, Kokorovec M, Vertovec M, Jarc D, Rupel A et al. (2001) *Paesaggio e architettura rurale carsica*. (Karst rural landscape and architecture). Ronchi dei Legionari: Ergon.

Khanna P (2016) *Connectography: le mappe del future ordine mondiale*. (Connectography: maps of the future world order). Rome: Fazi Editore.

Klemenčič V (1979) Urbanizzazione spaziale e minoranze etniche nel centro Europa. (Spatial urbanization and ethnic minorities in central Europe). In T De Mauro (Ed), 59–70. *Conferenza Internazionale sulle Minoranze 10-14 Luglio 1974*. Trieste: Atti della Conferenza, Tipografia Villaggio del Fancillo.

La Cecla F (1996) *A che servono le frontiere?* (What are borders for?) In A Gasparini, M Zago (Eds), 298–306. *Al di là dei Nuovi Muri. L'Europa Collaborativa che Viene dalle Città di Confine*, Milan: Franco Angeli.

Valussi G (1963) *I tipi del paesaggio carsico.* (The types of the karst landscape). Como: Società Geografica Italiana, Como.

Valussi G (Ed) (1974) *Gli sloveni in Italia*. (Slovenians in Italy). In *Minoranze a Confronto. Contributi alla Geografia delle Minoranze Etniche sui due Lati della Frontiera Italo-Jugoslava*. Udine: Pubblicazioni dell'Istituto di geografia dell'Università di Udine.

Zanini P (1997) *Significati del confine. I limiti naturali, storici, mentali*. (Meanings of the border. The natural, historical and mental limits). Milan: Mondadori.

Zanirato C (1999) *Architettura al limite. Il limite dell'architettura, l'architettura del limite*. (Architecture to the limit. The limit of architecture, the architecture of the limit). Firenze: Alinea.