LANDSLIDE GEOHAZARD FOR PIPELINES OF NATURAL GAS TRANSPORT

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Abstract

Landslides represent a significant hazard for pipelines because they can generate permanent ground displacement and tend to result in complete failure or significant leaks, major environmental impacts and long periods of service disruption. Hence, landslide-related incidents are regarded as a significant operational risk. The paper mainly focuses on the assessment of landslide hazard along or across a natural gas pipeline project and on the identification of these hazards, mostly in the field. Whether the "expected" landslide event reaches the Right of Way (RoW) and impacts the pipeline, is influenced by the nature and size of the expected landslide event, controlled by the site geology and geomorphology, the proximity of the existing landslide feature to the pipeline and the position of the pipeline relative to the landslide. Landslide hazard assessment is used to identify "hot spots" along the pipeline route where re-routing or risk reduction measures must be prioritised. When landslides that can threat the pipeline integrity cannot be avoided, more detailed site evaluation is required to support the design and construction of mitigation measures.
Keywords: *Right of Way (RoW), failure modes, pipeline vulnerability, landslide identification, mitigation measures, pipeline integrity.*

Περίληψη

Οι κατολισθήσεις αποτελούν έναν σημαντικό κίνδυνο για τους αγωγούς, επειδή μπορεί να προκαλέσουν εκτός από καταστροφή, μόνιμες παραμορφώσεις και να οδηγήσουν σε διαρροές, περιβαλλοντικά προβλήματα και μεγάλες περιόδους διακοπής της λειτουργίας. Ως εκ τούτου, τα περιστατικά που σχετίζονται με κατολισθήσεις αντιμετωπίζονται ως ένας ιδιαιτέρως σημαντικός κίνδυνος για την λειτουργία του αγωγού.

Η παρούσα εργασία επικεντρώνεται κυρίως στην αξιολόγηση της επικινδυνότητας έναντι κατολισθήσεων κατά μήκος ή εγκάρσια ενός αγωγού φυσικού αερίου και στην, κυρίως στο πεδίο, αναγνώριση αυτών των κινδύνων. Το αν η "αναμενόμενη" εκδήλωση κατολίσθησης θα φτάσει την χάραξη του αγωγού και θα τον επηρεάσει, εξαρτάται από το είδος και το μέγεθος της ενδεχόμενης κατολίσθησης, στοιχεία που ελέγχονται προφανώς από τη γεωλογία και τη γεωμορφολογία, ή και την θέση του αγωγού σε σχέση με ενδεχόμενη προυπάρχουσα κατολίσθηση. Η αξιολόγηση της επικινδυνότητας έναντι κατολίσθησης προσδιορίζει σε πρώτη φάση επικίνδυνες περιοχές (hot spots) κατά

μήκος της διαδρομής του αγωγού, όπου πρέπει να δοθεί προτεραιότητα είτε σε μέτρα θεραπείας και μείωσης επικινδυνότητας είτε σε αλλαγή χάραξης. Όταν κατολισθήσεις που ενδέχεται να επηρεάσουν την ακεραιότητα του αγωγού δεν είναι δυνατόν να αποφευχθούν, απαιτείται λεπτομερής έρευνα και αξιολόγηση των επί τόπου συνθηκών για την υποστήριξη του σχεδιασμού και της κατασκευής των μέτρων θεραπείας.
Λέξεις κλειδιά: *κατολίσθηση, επικινδυνότητα, αγωγός φυσικού αερίου, χάραξη αγωγού, μέτρα θεραπείας.*

1. Introduction

Landslides and unstable ground pose a significant threat to buried natural gas pipelines since they can generate permanent ground displacement (PGD) along or across the pipeline alignment. PGD is an important concern since a buried pipeline must deform both axially and in bending in order for the movement of the surrounding ground to be accommodated (Nyman *et al.*, 2008).

Pipeline rupture is not uncommon in incidents caused by landslides. As such, landslide-related incidents often result in leaks that may have severe environmental impact as well as long periods of operational stoppage (e.g. Savigny *et al.*, 2005). Regarding pipelines running through mountainous areas, statistics show that landslides are the most common cause of pipeline rupture and as such the most significant operational risk (e.g. Sweeney *et al.,* 2005).

It is generally accepted that avoidance of landslide-prone areas is the most effective hazard reducing option both in terms of cost and time saving. Sweeney (2005) points out that this is due to the fact that the investigation and the subsequent stabilisation of a significant number of landslide areas is not a practical undertaking mainly due to time and cost constraints. Accordingly, in mountain regions, the presence of landslides or the presence of landslide-prone areas is a quite important factor for the finalisation of the pipeline route Landslide hazard assessment is used to identify "hot spots" along the pipeline route where re-routing or risk reduction measures must be prioritised. In cases where "hot spot" areas cannot be avoided, detailed evaluation of all site conditions is necessary for the support of the design and construction of mitigation measures.

2. Standards and Definitions

An approach for the assessment of the pipeline risk due to landsliding follows international best practice for landslide risk assessment, as defined in Fell *et al.* (2005) and Lee *et al.* (2014). The ISSMGE TC32 - Technical Committee on Risk Assessment and Management defines hazard as the probability that a particular danger (threat) occurs within a given period of time (ISSMGE 2004). An initiating trigger event is an incident (or combination of incidents) that causes a landslide event (e.g. strong earthquake or heavy rainfall). A damage case is a level of damage resulting from the impact of a landslide on the pipeline (e.g. exposure, bending and buckling, rupture). Risk is usually expressed as the product of the probability of an event (e.g. pipeline rupture) and its adverse consequences. The assessment of risk along a pipeline route, though, is not in the scope of this paper.

3. Landslide hazard

3.1. Landslide hazard - general

The hazard associated with landslides is determined by the type of movements which can be expected to occur and their potential to produce adverse consequences. Three main categories of landslide events can be recognised:

- first-time failures of previously un-sheared ground, often involving the mobilization of the peak strength of the material. Such slides are often characterised by large, rapid displacements.

- reactivation of pre-existing landslides where part or all of a previous landslide mass is involved in new movements, along pre-existing shear surfaces (Figure 1).
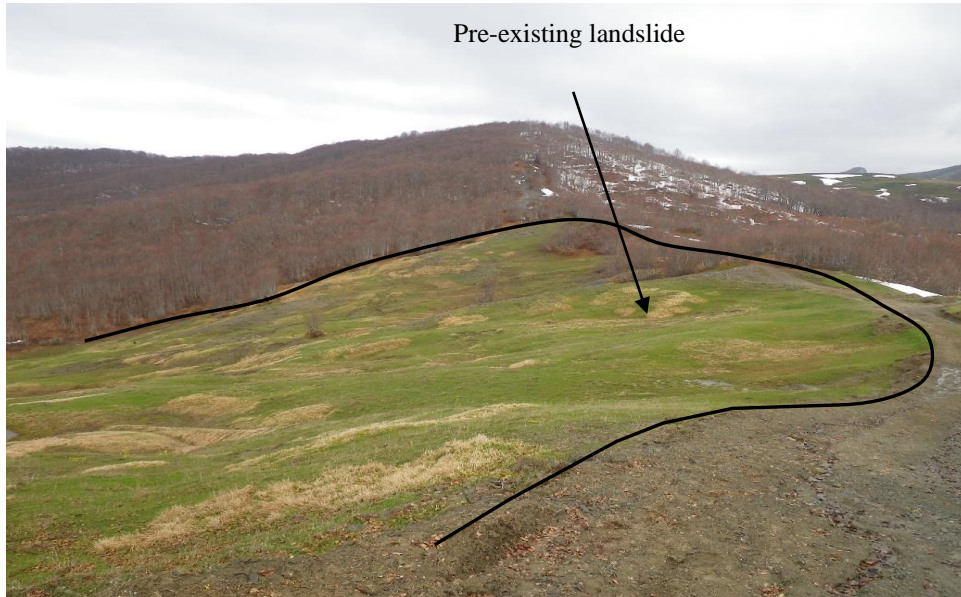

Pre-existing landslide

Figure 1 - Pre-existing landslide on the flank of a ridge, where a pipeline route runs.

- expansion of a pre-existing landslide, typically involving uphill or lateral retrogression of the main landslide head (Figure 2 and Figure 3), or the downhill advance of debris lobes on the toe area.

Tension cracks

Figure 2 - Tension cracks along a ridge flank, indicating potential for upslope retrogression of pre-existing landslides.

Figure 3 - Very steep landslide back scar extending to the ridge crest, with potential for further upslope retrogression.

For an existing landslide or slope to have the potential for future movement there must be a credible initiating event that causes landslide movement. Examples include:

- increased pore-pressures associated with periods of heavy rainfall or snow melt;

- seismic ground shaking due to moderate to strong earthquake events;

- removal of support by erosion of the landslide or slope toe (e.g. by a river or during excavation);

- increasing the driving force by loading the head of the landslide or slope (e.g. by the accumulation of debris from hillside debris avalanches or fill placement during construction).

Whether the "expected" landslide event reaches the Right-of-Way (RoW) and impacts the pipeline is influenced by the nature and size of the expected landslide event (controlled by the site geology and geomorphology), the proximity of the existing landslide feature to the pipeline and the position of the pipeline relative to the landslide (i.e. upslope, beyond the lateral margin, crossing or downslope of the toe).

Finally, unforeseen landslide problems could still arise during the construction and operations phases of a pipeline project.

A 3-D block diagram illustrating the landslide hazard in a pipeline route is presented in Figure 4.

3.2. Pipeline vulnerability

Not all landslide events that reach the pipeline will cause rupture. Some may only lead to exposure, whilst in other cases the damage may be limited to bending or buckling. A number of simple failure types have been developed for pipeline, based on industry experience (Nyman *et al.,* 2008; Lee *et al.,* 2009; Young and Lockey, 2013). These are:

1. **Lateral and vertical displacement**. Pipeline rupture as a result of differential horizontal and/or vertical movement of the landslide main body, upslope retrogression of the main scarp or failure of the flanks. The potential for pipeline displacement is a function of landslide

depth, the behaviour of the materials, the speed of movement and the cumulative displacement that could occur over time.

2. **Spanning**. Pipeline rupture as a result of removal of support along a significant length (e.g. greater than 30m) due to retreat of the landslide main scarp (upslope retrogression) or failure of the landslide flanks (lateral expansion). The potential for spanning is a function of the vertical displacement of the landslide mass and retreat of an eroding scar across the pipeline alignment.

3. **Loading.** Pipeline rupture due to stresses induced after burial by debris. This failure mode depends on the depth of burial and the weight of the material that acts upon the pipeline.

4. **Impact**. If the pipeline is exposed, impulse due to the momentum of falling boulders may result in pipeline rupture. In general, buried pipelines are less vulnerable to this failure mode. As this is a case of momentum and impulse, the height from whence the boulder originated (i.e. the impact speed) and the mass of the boulder are the defining parameters.

3.3. Landslide identification

The work on landslide identification, both at the preparation stage and at field, must be to continuously look for key elements that signify the existence of an active landslide or an unstable area. These key elements are presented in the following paragraphs. It is highlighted though that a final assessment of the level of hazard and risk for the pipeline due to potential landslides along the route must be undertaken by experienced geologists.

3.3.1. Desk study

The desktop study involves three main procedures to prepare an appropriate landslide-prone area inventory.

5. Identification of possible old landslide areas from the topographic map- Sudden changes of slope angle, flat areas or bulge on slopes (square, vis-à-vis contour lines).

6. Identification of possible old landslide areas from satellite images - bare with no vegetation and/or steep slopes.

7. Identification of surface water ponds and lakes.

3.3.2. Field identification

The field work must be executed where ever possible and mostly on the ridges along the pipeline route, following a primary identification of possible geohazard landslide areas from the topographic maps and satellite images. As a result of a field survey, new landslide geohazard areas can be identified and highlighted landslide geohazard areas, identified from the desk study, can be confirmed, delineated or discarded. The -as accurate as possible- adjustment of the boundaries of each landslide is very helpful for the selection of the optimum route and for the subsequent risk assessment. The field study must involve several procedures and observations, in order to define the actual spatial, geological and geotechnical features of the finally derived landslide areas. Such observations can be:

- Fresh cuts or ruptures along the slope, arch-shape or transversal to it (Figure 4)
- Wide undulating morphological features (Figure 5)
- Deformed vegetation - creep (Figure 6)
- Irregular topography with small hills and back-tilts along the slope (Figure 7)
- Springs, reservoirs of water (small lakes) in the middle of the slope
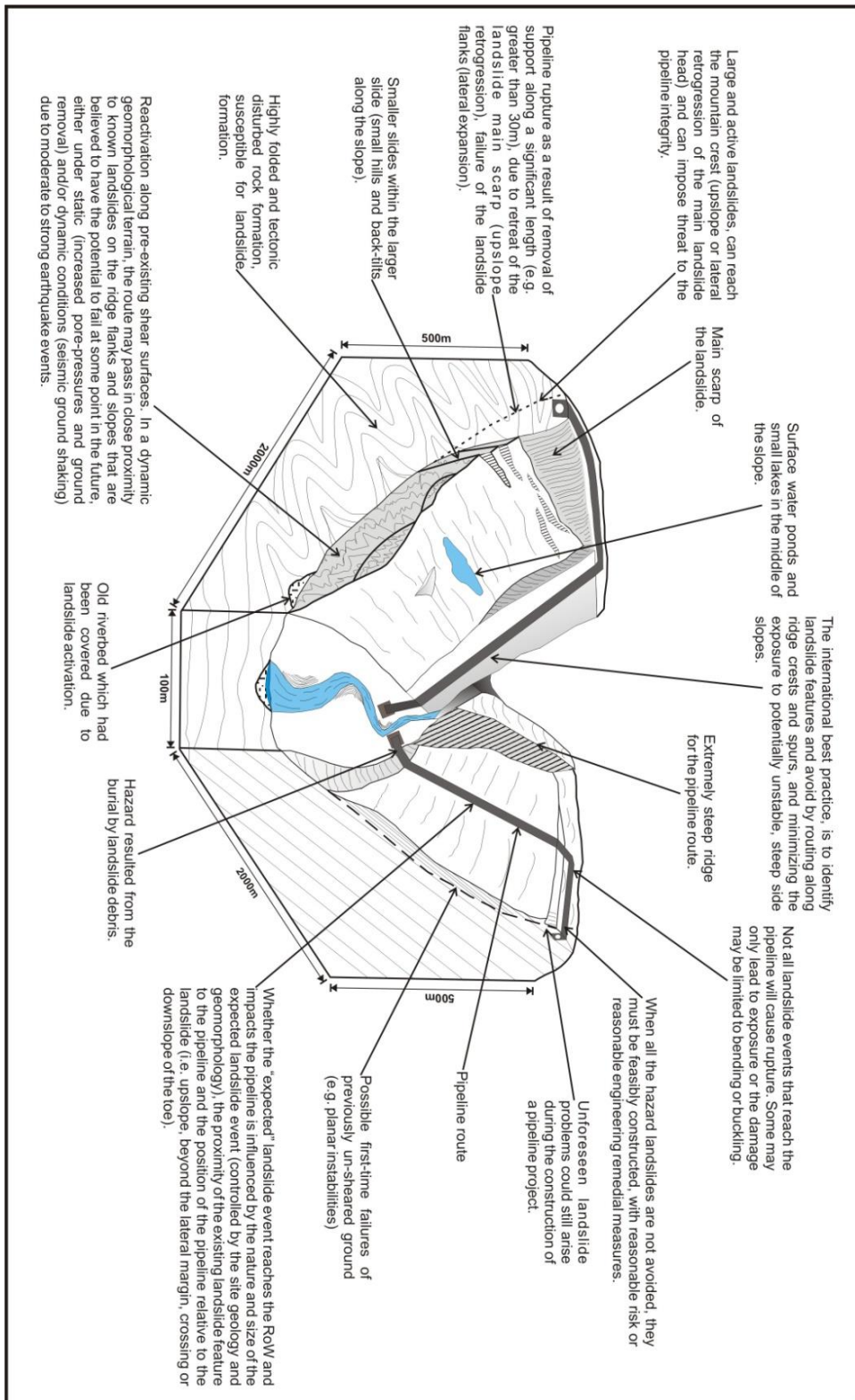 Sudden changes of slope angle, flat areas or bulge on slopes

Figure 4 - A block model illustrating the landslide hazard in natural gas pipelines.

Figure 5- Fresh cracks.

Figure 6 - Opening at the top and parallel to the ridge indicating movement.

Figure 7 - Deformed vegetation due to landsliding. The knick of the trunk points to the movement direction.

Figure 8 - Visible irregularities in topography.

Characteristics about the quality of the rock mass (lithology, rock mass structure, weathering and extent of weathering mantle, strength, joint characteristics, water presence) should be identified and recorded. For the understanding of the ground behaviour developing the slope instabilities, a standardization of the qualitative engineering geological characteristics and the assessment of the behaviour in slope stability for the identified rock masses should be assessed.

3.4. Development of geotechnical sections for the analysis

In some cases, a geohazard should be geotechnically investigated in more detail to study the parameters and the conditions under which the slope would fail and could threat the pipeline integrity. Such spots can be the ones that are not avoided by the re-routing or some geohazards that are evaluated with moderate or low risk. In this case, apart from the field work, a geotechnical investigation program must be planned. The methodology that can be followed by an engineering geological group, for the development of geotechnical profiles includes the following basic steps for the studied geohazard area:

- The evaluation of all available data from previous studies and field inspection (topographical, seismological, seismotectonic, geological and geotechnical)

- The statistical analysis of all available engineering geological and geotechnical data (laboratory tests, rock mass classification), per individual area

- The elaboration of spatial geological data from sampling boreholes and in situ observations (superficial layers, extent of weathering mantle, bedrock etc.)

- The final proposal of geotechnical profiles which include the geometry of the slope, the stratigraphy of the area, the geotechnical properties for each engineering geological formation and seismological info of the site specific area

4. Mitigation measures

Rerouting options should be examined as a primary mitigation measure in order to avoid areas with large scale and active landslides, since they present a threat to the pipeline integrity (Figure 8).The international best practice, is to identify landslide features and avoid by routing along ridge crests and spurs, and minimising the exposure to large and active geohazard landslides, potentially unstable and steep side slopes.

Nevertheless, due to design and site-specific constraints, the selected route may not avoid all identified geohazard areas and as such, it may not be possible to eliminate the exposure to all landslide risks. Accordingly, the route may pass in close proximity (<50m) to either known landslides or potentially unstable areas.

The risk profile is expected to be dominated by upslope expansion of existing landslides, resulting in loss of ridge crest and pipeline rupture. However, there remains a possibility that new "first-time" landslides could develop under static and/or seismic conditions, especially on steep ridge flanks areas. This route should be feasibly constructed, with reasonable risk or reasonable engineering remedial measures. The risk could be significantly reduced through implementation of mitigation measures, such as minor adjustment to the route (to increase the set-back distance from the pre-existing landslide head), the construction of structures to isolate the pipeline from the effects of future landsliding (e.g. pile walls) or reduce the likelihood of future damaging ground movements (e.g. geotechnical slope drainage).

When the pipeline runs along the foot of an active and large landslide, the geohazard can be avoided by tunnelling below the sliding mass or by protecting the pipeline with engineering measures from a possible loading from landslide, constructed next to the river.

Monitoring may be required during construction and operation of the pipeline in geohazards of moderate or high risk that have not been avoided.

5. Discussion

The avoidance of significant landslides that cross mountain terrain for the pipeline RoW is the most important outcome of the routing process. The assessment must be based on extensive field work evaluation of all findings along the pipeline route, desk study of available data and ground investigation campaigns.

It is important to be realistic about the precision and reliability of the assessed levels of hazard in the various identified sites. The results should provide a "high level" indication of how landslide hazard and risk is expected to vary through a mountain terrain and have to conclude identifying "hot spots" along the route where risk reduction measures should be prioritised. This information can be used to perform numerical analyses for slope stability assessment and the corresponding pipeline verification, in order to provide quantitative support to an expert classification of landslide risk. This assessment though, cannot be however a substitute for more detailed site evaluation that would be required to support the design and construction of mitigation measures at the critical slopes according to EN1997 and EN1998.

Figure 9 - Overview of a geohazard area (orange line) in close proximity with a proposed pipeline RoW (red line). In such cases, avoidance by rerouting is the preferred option. When the landslide hazard is not avoided, it must be feasibly constructed, with reasonable low risk or reasonable engineering remedial measures.

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GROUNDWATER QUALITATIVE CHARACTERISTICS OF MYGDONIA BASIN. INVESTIGATION OF THE POLLUTION SOURCES AND SUITABILITY FOR HUMAN USE

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Abstract

Mygdonia drainage basin encloses lakes Volvi and Koronia which are protected by the RAMSAR Convention. Lake Koronia is an example of global environmental destruction. The entire area is affected from agricultural and industrial activities (mainly in the past) and has suffered severe human impacts. Groundwater sampling was conducted twice a year (dry/wet period), during the years 2013-2015. The results of the analyses were spatially distributed and the appropriate maps were constructed. According to the quality parameters distribution the possible pollution sources of the aquifers were investigated. Hydrochemical diagrams were used for the water types classification and the suitability for drinking or irrigation purposes etc. The EU Water Framework Directive 2000/60 and the national legislation were also used. Excess of the maximum permissible levels for drinking water were observed mainly for nitrates in a large extent of the basin as a result of the bad agricultural practices in the area. Sporadic high concentration values were recorded for other parameters and are associated with human activities or geology. Measures in order to prevent a further degradation of the groundwater quality are proposed in the paper.
Keywords: Nitrates, fertilizers, lakes.

Περίληψη

Η λεκάνη απορροής της Μυγδονίας περικλείει τις λίμνες Βόλβη και Κορώνεια που προστατεύονται από τη Σύμβαση RAMSAR. Η λίμνη Κορώνεια είναι ένα παράδειγμα παγκόσμιας περιβαλλοντικής καταστροφής. Ολόκληρη η περιοχή επηρεάζεται από γεωργικές και βιομηχανικές δραστηριότητες (κυρίως στο παρελθόν) και έχει υποστεί σοβαρές επιπτώσεις από τις ανθρωπογενείς δραστηριότητες. Πραγματοποιήθηκε δειγματοληψία υπογείου νερού δύο φορές το χρόνο (ξηρή/υγρή περίοδο), κατά τη διάρκεια των ετών 2013 - 2015. Τα αποτελέσματα των αναλύσεων κατανεμήθηκαν χωρικά και δημιουργήθηκαν οι κατάλληλοι χάρτες. Σύμφωνα με την κατανομή των ποιοτικών παραμέτρων διερευνήθηκαν οι πιθανές πηγές ρύπανσης των υδροφόρων στρωμάτων. Χρησιμοποιήθηκαν υδροχημικά διαγράμματα για την ταξινόμηση των δειγμάτων σε τύπους νερού και την καταλληλότητα για ύδρευση ή άρδευση κλπ. Η Οδηγία Πλαίσιο 2000/60 της Ευρωπαϊκής Ένωσης για τα νερά και η εθνική νομοθεσία χρησιμοποιήθηκαν επίσης. Υπέρβαση των μέγιστων επιτρεπτών επιπέδων για το πόσιμο νερό παρατηρήθηκαν κυρίως για τα νιτρικά σε μεγάλη έκταση της λεκάνης ως αποτέλεσμα των κακών γεωργικών πρακτικών στην περιοχή. Σποραδικές υψηλές τιμές συγκέντρωσης καταγράφηκαν για άλλες παραμέτρους και σχετίζονται με τις ανθρώπινες

δραστηριότητες ή τη γεωλογία. Μέτρα, προκειμένου να αποφευχθεί η περαιτέρω
υποβάθμιση της ποιότητας των υπόγειων υδάτων προτείνονται στην παρούσα εργασία.
Λέξεις κλειδιά: *Νιτρικά, λιπάσματα, λίμνες.*

1. Introduction

Water resources are necessary for human living and are through time related to the development of the societies and their economic growth (Gannoulis, 2004). During the last decades, a progressive degradation of the groundwater quantity is recorded worldwide, due to the overpumping (in order to meet the increased irrigation demands) and a degradation of the quality characteristics that constitutes groundwater reserves unsuitable for human consumption or other uses. Mygdonia basin is a typical example of such bad water resources management. The need for more cultivated land during the decades of 1950 and 1960 led to artificial drying of the Vromolimnes (Lantza and Mavrouda). The intense cultivation of the plain parts of the basin, in combination with the change of the type of crops and irrigation practices, had as a result a deficient hydrological balance since the middle of the 1980 decade (Chatzipetros and Pavlides, 1998; Zalidis *et al.*, 2004). Many boreholes were drilled during that period especially in the sub-basin of Koronia in order to meet the irrigation demands. A continuous shrinking of the lake and degradation of aquifers water level was recorded with the exception of some rainy years (e.g. 2013-2014). During the same period, the fertilization of the cultivations and the lack of treatment facilities of the villages and local industries that operated in the area, had as a result the direct disposal of the untreated waste in the lake Koronia or the aquifers of the area degradating the qualitative characteristics of the water resources. The effects of the human activities in the past, made the necessity of an integrated water resources management plan clear to the stakeholders and policy makers of the area. Many measures have been implemented the last decades in order to restore the environment and to prevent any further degradation. The whole basin is recognized as a region of high ecological importance and it is protected by Common Ministerial Decision 6919/2004. The lakes Koronia and Volvi are part of a complex wetland of international importance that is protected by the RAMSAR Convention and the Macedonika Tembi Valley belong to the Natura 2000 Network (Economou *et al.*, 2008). Mygdonia basin have been studied by several researchers. The following are indicatively mentioned: Knight Piesold Ltd. and Karavokyris and Partners (1998), Zalidis *et al.* (2004), Tzimopoulos *et al.* (2005), Vafiadis (1991), Nimfopoulos *et al.* (2002). The aim of this paper is to investigate the current state of the quality characteristics of the basin's groundwater resources. The authors carried out a research in the area, during the years 2013-2015 in the frame of the research program with the title «Implementation of monitoring program of biotic and abiotic parameters and support of self-supervision to the Lakes Koronia Volvi Management Agency» that was funded by the Lakes Koronia Volvi Management Agency. The data that are presented in the paper are primary.

2. Study area

2.1. Geological setting

The Mygdonia basin is extending E-NE of Thessaloniki city at a distance of 10 km. It is a graben following an E-NW orientation and its surface is 2026 km^2 (Figure 1). From a geological point of view the greater part of the Mygdonian basin belongs to the Serbomacedonian massif and a smaller part to the Circum Rhodope belt (Mountrakis, 1985). The crystalline basement consists mainly of schist, gneiss, amphibolites, marbles and granites (Figure 2). According to Psilovikos (1977), Pleistocene sediments of a loose terrace system prevail in the margins of the graben and Holocene sediments in the middle area that constitute the Mygdonian system which is the upper unit of the basin. A pre-Mygdonian formation that outcrops in the south margins of the basin was deposited on the weathered bedrock. The Mygdonian unit consists of gravel, sand, sandy clays, alluvial deposits and river or torrential deposits that have a thickness greater of 100m in some locations (Sotiriadis *et al.*, 1983). The pre-Mygdonian system consist of crystalline bedrock, conglomerates, sandstones,

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silt- sand sediments, and red-beds that were deposited in Neogene (BRGM 1971). The thickness of these formations varies from 250m to 110m (Raptakis *et al.*, 1998; Raptakis *et al.*, 2000). According to geophysical survey (Thanasoulas, 1983) two main fault systems prevail in the area. The main orientation is NW-SE and SW-NE.
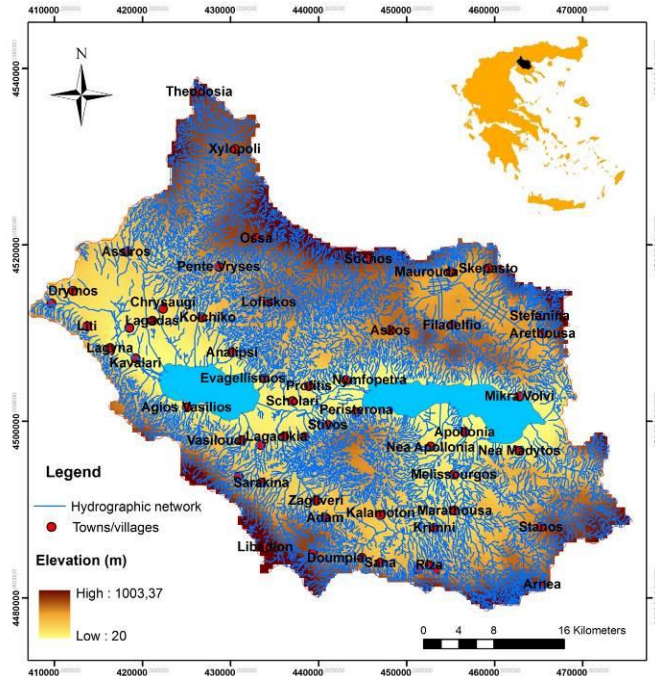

Figure 1 - Geomorphological map of Mygdonia basin.

2.2. Hydrogeological regime

The basin is divided in two sub-basins that comprise the lakes Koronia and Volvi respectively. The lakes are mainly recharged from the precipitation and the torrents of the basin. The water flow in the hydrographic network of the area has a seasonal character. The main aquifers of the basin are developed in the granular quaternary deposits of the plain parts. These deposits consist of alternating layers of sand and gravel, clays and silt. The thickness of these formations reaches up to the 400 m (OYTH-BRGM, 1973). At depth of 50 m from the ground surface a phreatic aquifer is developed. An impermeable zone from clay prevails at depths between 50 to 80 m and an unconfined aquifer extends from the depth of the 80m until approximately the depth of 500 m consisted of quaternary deposits and neogene clastic materials. According to Demiris (1994) the confined aquifer extends at the centre of the basin and its mean width is approximately 150m (Knight Piesold Ltd and Karavokyris and Partners, 1998). Vatseris (1992) suggested that there is no connection between the phreatic and the confined aquifer at the west part of Mygdonia but more recent data (Nimfopoulos, 2002) indicate that there is an interaction between them. The aquifers that are developed in the crystalline formations are encountered in depths greater than 30 m at the boundaries of the basin. They are of relatively small capacity (from 10 to 25 m^3/h). They discharge in the loose quaternary deposits (Nimfopoulos, 2002).
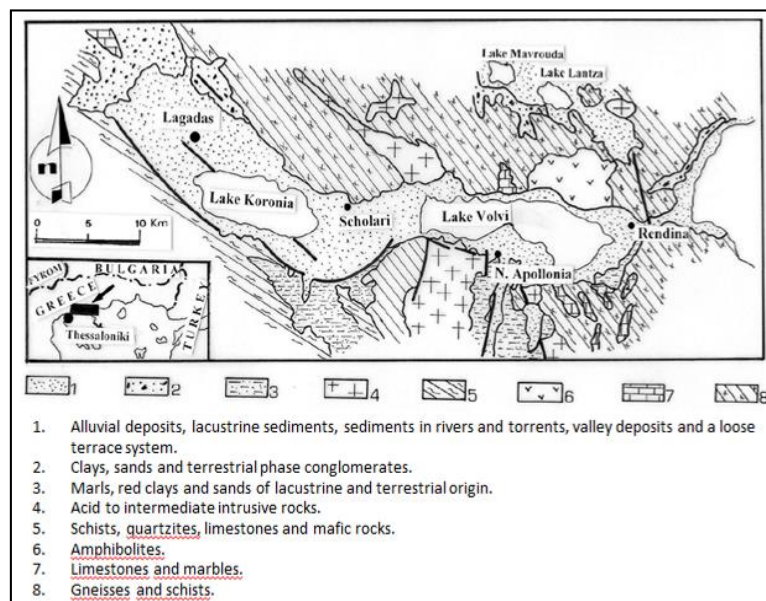
The legend below the map:

1. Alluvial deposits, lacustrine sediments, sediments in rivers and torrents, valley deposits and a loose terrace system.
2. Clays, sands and terrestrial phase conglomerates.
3. Marls, red clays and sands of lacustrine and terrestrial origin.
4. Acid to intermediate intrusive rocks.
5. Schists, quartzites, limestones and mafic rocks.
6. Amphibolites.
7. Limestones and marbles.
8. Gneisses and schists.

Figure 2 - Geological map of the study area (Nimfopoulos *et al*., 2002).

3. Materials and Methods

In the year 2013 a network of boreholes appropriate for water sampling was designed. The sampling was conducted two times a year for a time period of three years (2013-2015). The sampling period of each year was affected by the weather conditions that determined the beginning of the irrigation period. The water samples of the boreholes depict the resultant condition of both aquifers (phreatic and confined). In situ measurements of Electrical Conductivity and pH were carried out. Chemical analyses were conducted at the Laboratory of Engineering Geology and Hydrogeology, A.U.Th. The concentration of the following ions was determined: Na, K, Ca, Mg, HCO_3, SO_4, Cl, and NO_3. There was an effort in order the network of the boreholes to remain constant during the three years, however a small number of them had to be replaced, with other in close distance and similar characteristics. Thematic maps depicting the spatial distribution of the qualitative characteristics were designed using GIS software. The suitability of the water for irrigation use was examined using S.A.R. (Richards, 1954) and Wilcox (1955) diagrams. The possible groundwater pollution sources were investigated during field observation and from literature review, according to the results of the aforementioned data.

4. Results and discussion

The results of the chemical analyses and the time period of the groundwater sampling are depicted in Table 1. The spatial distribution of the Electrical Conductivity, sodium and nitrates is depicted in the Figures 3, 4, 5. The aforementioned parameters were selected as the most indicative of water pollution for the area, but a brief description of all the measured is given in the text. Regarding the Electrical Conductivity there is no significant fluctuation for the different sampling periods in the values of this parameter. The highest values were measured in the west part of Lake Koronia at the village of Irakleio (values higher than 1200 µS/cm) and are attributed to human activities. According to testimonies of the residents an industry in the sector of textile dyeing operated in the area for many years. The wastes were disposed in a surface channel. Pollution of the aquifers due to the interaction with the waste is possible. In the southern part of the area close to the village Adam high values of electrical conductivity were observed due to the geological formations of the area. *The magnesium values remained constant during the water sampling periods. H*igh concentrations of

sodium were recorded west of Lagadas (Irakleio), north of Koronia, west and south of Volvi lake (Figure 4) at all the sampling periods. These values are related to human activities (west of Lagadas) and to the existence of Lagadas and Nymfopetra geothermal fields (north of Koronia, west of Volvi). The existence of livestock units could possibly constitute a point pollution source, since they use salt. Regarding the area south of Volvi, according to Kokkinakis *et al.* (2000) the lake Volvi is recharged from thermometallic springs. There is a possibility these samples to be affected by the lake water (Zabour, 2010). As for the potassium ions the values are low and nothing notable appeared throughout the whole basin. Concentrations values of sulfate ions appear fluctuation between the years 2013 and 2015. The highest values were recorded at the south part of the basin, close to the village Adam area and they are considered to be of geogenic origin. The high values that were observed in the plain part of the basin were found near to the geothermal fields area. The chloride values are generally low with the exception of two samples west of Lagadas and west of Volvi. The bicarbonate ions don't show significant intra-or inter annual variation and the values correspond to those of typical natural waters. Many samples, show values that exceed 50 mg/l in nitrate ions (Figure 5), which constitute the maximum permissible limit for drinking water according to the Directive 2006/118 EC, the Join Ministerial Decision 39626/208/E130 and the Ministerial Decision 1811/2011 (Official Government Gazette 3322 B/2011). These high values are distributed to the entire basin and are attributed to the fertilization of the cultivated land, to the lack of wastewater treatment facilities of the settlements and in some cases to the livestock units.

The suitability of the water samples for irrigation purposes was examined with the use of S.A.R. (Richards, 1954) and Wilcox (1955) diagrams. The results of the year 2015 are presented, since there was no significant change to the classification of the samples during the three years period. As it is shown in the Wilcox diagram (Figure 6) the samples are suitable for irrigation and are classified as "Excellent to good" to "good to permissible". According to S.A.R. diagram (Figure 6), the majority of the samples are classified as "of medium quality".

Table 1 - Minimum, Maximum and mean values of the main chemical factors for the period 2013-2015 at Mygdonia basin.

|		EC (µS/cm)	pH	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	SO$_4$ (mg/l)	Cl (mg/l)	HCO$_3$ (mg/l)	NO$_3$ (mg/l)
May 2013 (20 samples)	Min	440	6.98	12	6.8	28	1	21	9	170	10
	Max	1277	7.97	150	59	162	9	141	54	435	119
	Mean	811.3	7.33	76.43	24.8	55.6	3.3	60.5	30.9	299	41.5
Sept 2013 (19 samples)	Min	426	7	35.4	9.1	21.2	1.2	20	9	200	2.2
	Max	1277	8.2	146.7	85	115	5.2	133	55	450	112.6
	Mean	780	7.48	74.01	26.8	46.6	2.6	56.3	27.5	304	29.3
May 2014 (17 samples)	Min	444	7.07	20.4	10	16	1.7	26	8	216	0.4
	Max	1971	8.04	96	67.9	240	5.9	280	234	580	110
	Mean	916.4	7.46	58.5	26.86	81.8	3.1	100.5	48.6	307	33.4
Sept 2014 (26 samples)	Min	259	6.29	21.2	6.8	18.6	0.8	14	12.8	158	4.4
	Max	2010	8.04	88	72	233	6.1	252	217	513	75.2
	Mean	889	7.48	53.7	33.44	66.9	3.02	76.3	38.9	302	36
June 2015 (28 samples)	Min	416	6.89	32.8	6	29	0.6	16	12	141	4.4
	Max	1900	7.82	174	64.5	240	5.4	470	238	475	155.8
	Mean	914.9	7.44	79.06	29.03	70.9	3.03	108	47.5	293	41.4
Aug 2015 (25 samples)	Min	411	7	34.4	7.6	21	0.6	22	7.8	146	3.1
	Max	2190	8.14	180	75	202	5.2	300	333	510	118.8
	Mean	870.1	7.56	81.11	27.05	66.1	3.1	72	41.8	302	41.7
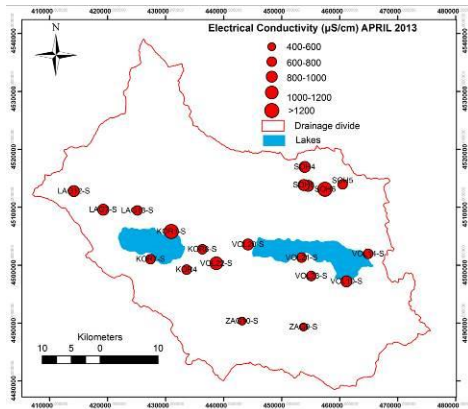
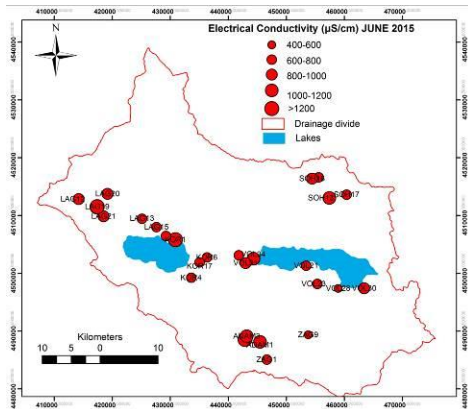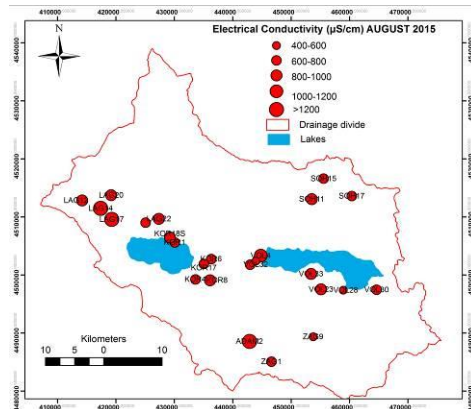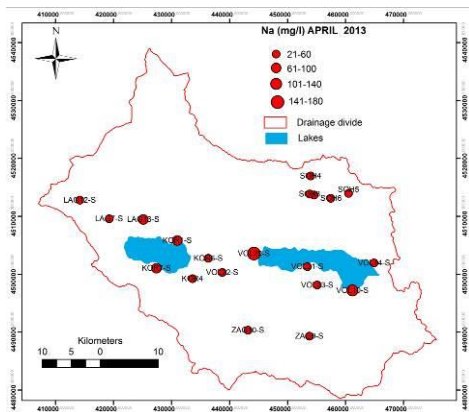May 2013   September 2013
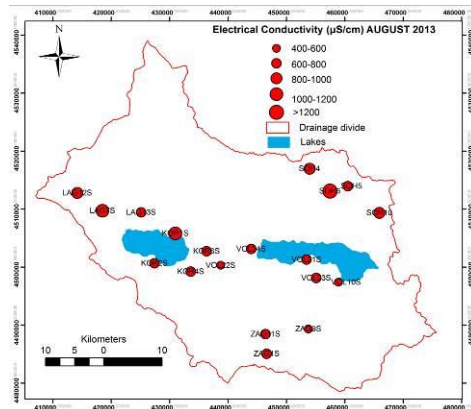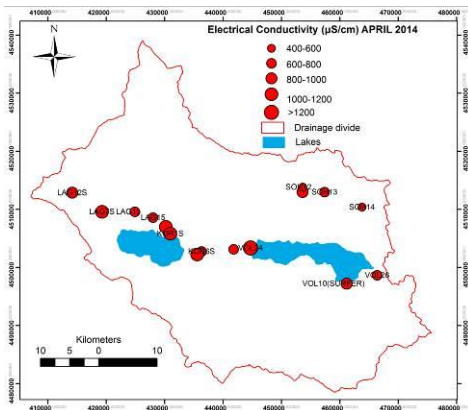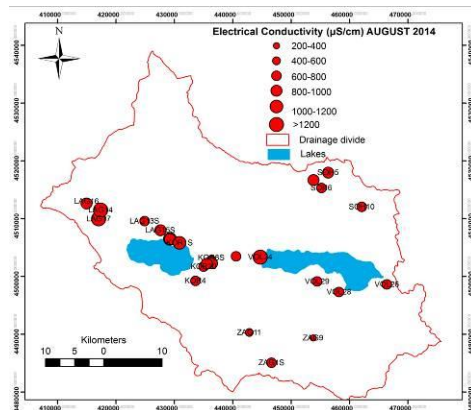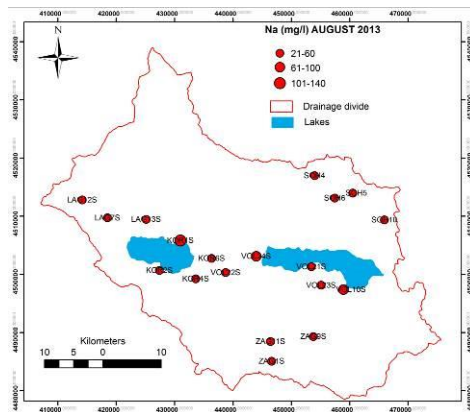
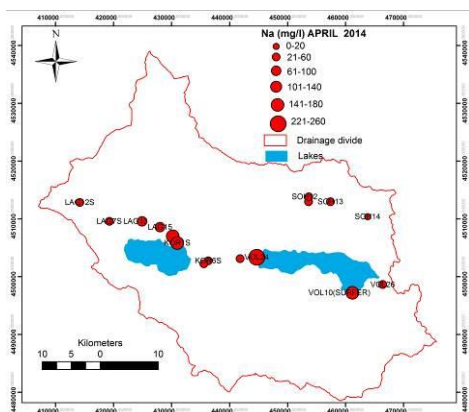May 2014   September 2014

June 2015   August 2015

Figure 3 - Spatial distribution of the electric conductivity (μS/cm) in the study area.

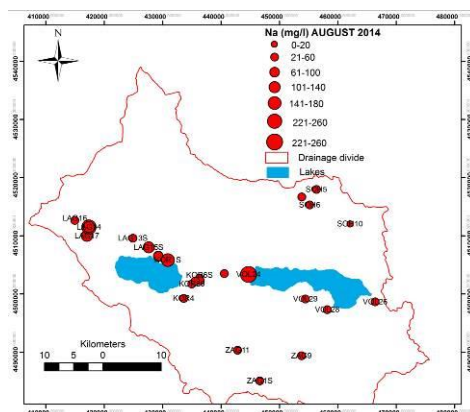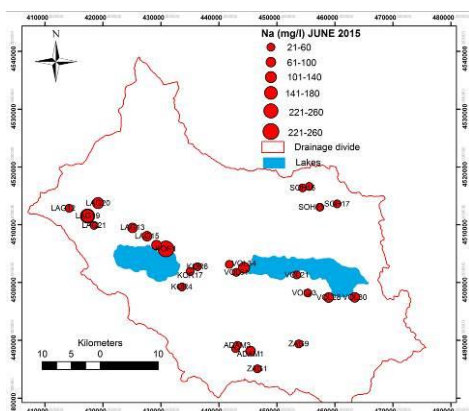Figure 4 - Spatial distribution of the Na - ions (mg/l) in the study area.

May2013

September 2013

May 2014

September 2014

June 2015

August 2015

Figure 5 - Spatial distribution of the nitrate ions (mg/l) in the study area.
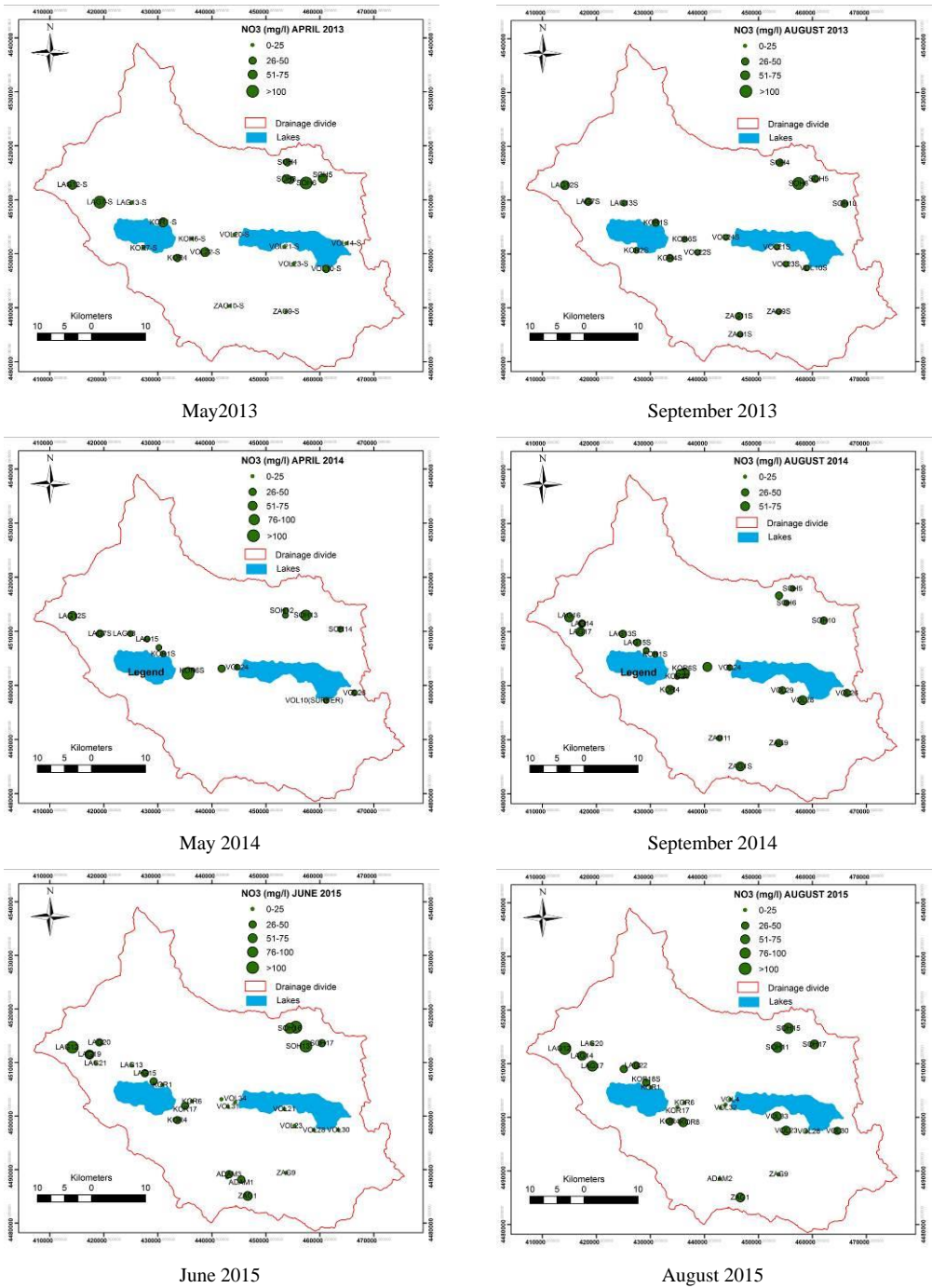
June 2015

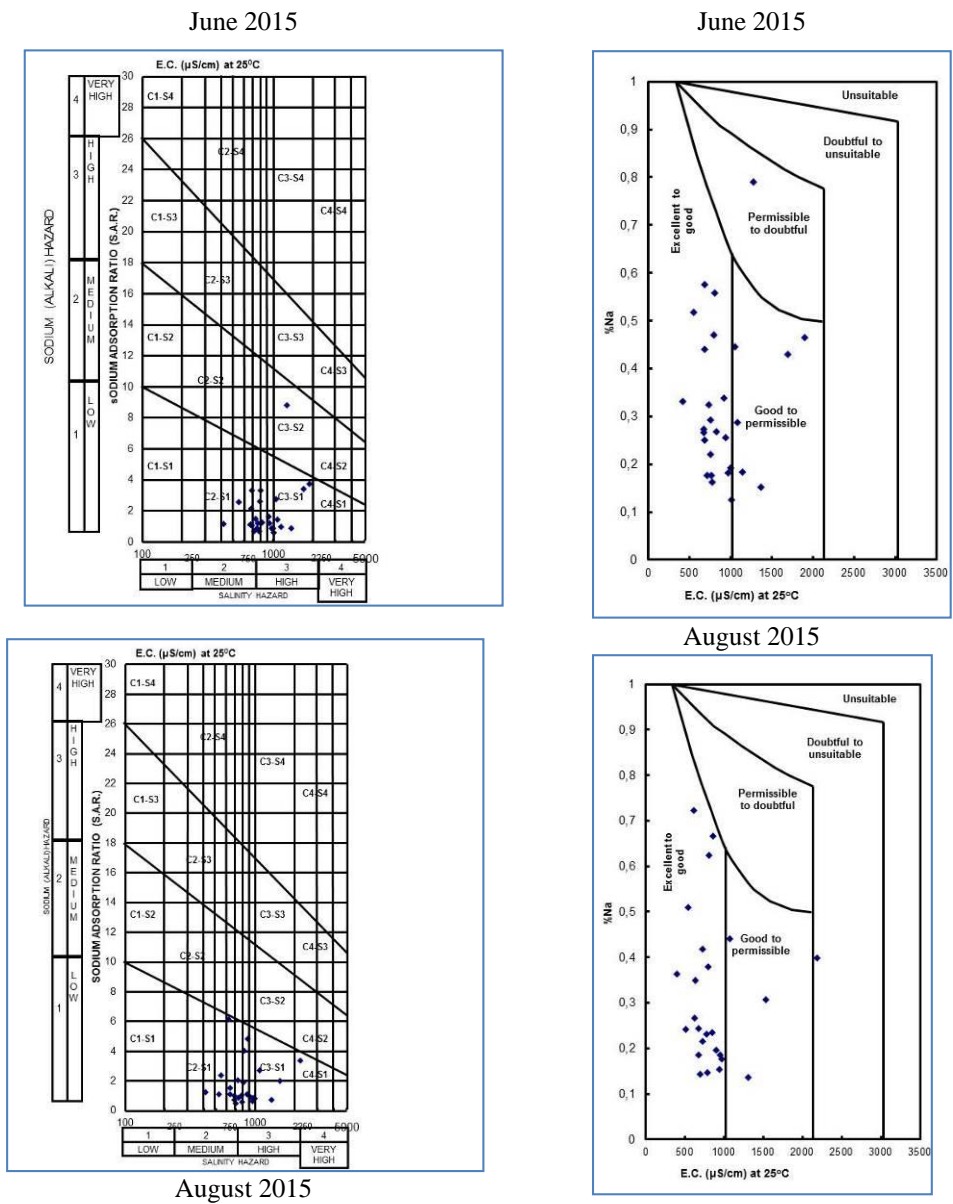June 2015

August 2015

August 2015

Figure 6 - SAR and Wilcox diagrams for the year 2015.

5. Discussion and conclusions

According to the results of this paper high values of Electrical Conductivity, nitrates, sodium and sulfates were recorded for an adequate time period. The fertilization of cultivated land, the disposal of untreated waste from industries and settlements and finally the live stock units operation are the main anthropogenic activities that affect the groundwater quality. The existence of three geothermal fields (Lagadas, Nymfopetra, Apollonia) probably affects the quality of the samples close to the two lakes area. In order to prevent any further degradation a number of measures should be proposed to reduce the impact of anthropogenic activities. An appropriate network should be established by the competent authorities to monitoring groundwater qualitative characteristics and pollution sources. Modern agricultural practices and irrigation techniques should be implemented in order to decrease

the groundwater quantities used for agriculture and thus the additional pressure to the aquifers. Further studies regarding the reuse of the wastewater (e.g. from industries or treatment plants) after treatment for irrigation purposes should be carried out. Finally, an integrated rational water management plan should be designed and applied aiming at sustainability of groundwater resources

6. Acknowledgments

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