**Fate of water treatment residual: an entire profile of Ireland regarding beneficial reuse**

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**Abstract**

Ireland's water treatment residual (WTR) production rate and reuse situation was investigated to complement the novel research on WTR reuse development in University College Dublin, Ireland. The resulting GIS maps reveal the state of WTR production, disposal and beneficial reuse throughout the country. The total WTR production in Ireland is 15,679 tonnes of dry solids per annum with over 90% of WTR being aluminium-salt-coagulated WTR. Only 8% of WTR is recycled or reused via composting, landspreading, cement manufacturing, constructed wetlands and quarry remediation. The authors recommend that there be further attempts to use WTR in constructed wetlands and cement manufacturing in Ireland.

*Keywords:* Alum-water treatment residual, constructed wetland, reuse, Ireland

## 1. Introduction

One of the most interesting industrial by-products is water treatment residual (WTR), which refers to the by-product generated inevitably worldwide from the production of drinking water in water treatment plants. The majority of the WTR is landfilled since it is regarded as a by-product of little known reuse value

[1]. The components of WTR are colour, turbidity, hardness and varied concentrations of organics and microorganisms in the raw water. More importantly, the WTR contains coagulant products and their residues. The residuals produced are Al-WTR and Fe-WTR when aluminium sulphate and ferric chloride are respectively or jointly used as coagulants. The landfill fate should be reconsidered. The WTR is predominantly composed of Al (29.7±13.3% dry weight in Al-WTR) or Fe (26.0±15.5% dry weight in Fe-WTR) ions [1]. Therefore, it is reasonable to believe that the WTR holds great promise for use as a valuable material in the treatment of wastewater as the ions enhance adsorption and chemical precipitation processes that remove various pollutants, especially phosphorus (P) since Al and Fe possess strong adsorption affinity with P from the chemistry point of view [2,3].

More recently, Makris *et al*. [4,5] and Camacho *et al*. [6] reported the WTR for other pollutant immobilization, such as perchlorate and arsenic. Therefore, beneficial reuse of such residual has become an area in environmental sustainable research and application. In addition, compared with other industrial by-products, the easy, local and huge availability of WTR is a special feature of the substance that promotes its possible large application.

In the last six years in University College Dublin (UCD), Ireland there have been great efforts to study the reuse of dewatered Al-WTR as a material to develop a novel constructed wetland (CW) system, which uses Al-WTR as the main substrate to treat P-rich animal farm wastewater, thus making the WTR a value-added raw material for water pollution control [7]. It has been observed that Al-WTR can be a good low-cost adsorbent [8-10]; suitable growth medium for wetland plant [11] and a good carrier for biofilm attachment and development for wastewater treatment in CW system [7,12].

Constructed wetlands are seen as the ‘green’ wastewater treatment technique and have steadily grown in number in the last ten years for both research and practice worldwide [13]. The advantages of attractive appearance, lower energy consumption and good treatment efficiency of the CWs have been well recognised [13-15]. The novel reuse of Al-WTR as main substrate in CWs for wastewater treatment presents a more sustainable option than typical wastewater treatment approaches to use “waste” for wastewater treatment. In addition to reporting the novel research and development in UCD regarding the CW technology using Al-WTR as major substrate, this paper also extends the research/development to provide an entire survey with reasonably accurate facts and figures on the current profile across Ireland of the quantities and disposal/reuse pathways of such residual.

## 2. Toxicity and legislation regarding WTR reuse

Potential toxicity on crops and accordingly human beings is the most important issue regarding the WTR reuse. There is limited information available in the literature on the phytotoxicity potential of WTR on agriculture and horticulture, and some contradictions are apparent. Sotero-Santos *et al*. [16] did a comparative data analysis of the toxicity of Al-WTR and Fe-WTR and reported that there was no acute toxicity displayed by either substance, upon exposing *Daphnia Smiles* to them for 48 hours. Yet, long-term exposure to Fe-WTR did cause some mortality among the daphnids as well as decreasing their reproduction, while Al-WTR was less toxic than Fe-WTR. Babatunde *et al*. [11] characterized the Al-WTR. The electrical conductivity of the Al-WTR ranged from 0.104 to 0.140 dS/m, which is well below the 4 dS/m associated with reduced plant growth due to salinity [17]. Thus the Al-WTR can be considered non-saline and capable of supporting the plant growth [11]. It should be pointed out that despite variation in sludge properties studied, there was no relationship observed between the property variables and the degree of toxicity.

Further, Dayton and Basta [17] provided evidence, using the toxicity characteristic leaching procedure (TCLP) on selected WTR samples (although WTR is not hazardous material in the current legislation worldwide), that the heavy metal levels in the WTR were low enough to be consistent with non-hazardous waste metals. These studies indicate that toxicity levels in WTR are frequently low enough to raise little cause for concern. Forstner and Haase [18] reported on the release of metals from WTR using the pH-stat procedure and implied a pH-dependent release. Agyin-Birikorang *et al*. [19-21] examined extensively the long term application of WTR in soil for various forms of P immobilization ability. These researchers also investigated the limitation rate of WTR application regarding release of elements and metals from the applied

WTR. It appears that any concerns about the toxicity of the WTR arise only with respect to land use applications such as agriculture and horticulture, but not in regard to other categories of potential reuse such as for wastewater treatment. Therefore, research is needed to examine the toxic effects of the WTR because of its potential for beneficial reuse.

Four broad categories of use, which include more than 11 possible ways, have been identified and examined in our previous publication [1]. In most cases, these reuses draw upon the characteristics of the sludge which result from its component comprising coagulant products. The remnants of the aluminium sulphate or ferric sulphate coagulant render it potentially useful for the applications. Regarding the current legislation on WTR reuse, Irish waste management policy and legislation is based on directives developed at European Union level. The European Waste Catalogue classifies WTR as a non-hazardous waste, which thus may be disposed of in non-hazardous landfill sites. For example, a report by RPS Consulting Engineers on the Donegal Waste Management Plan [22] states that, in Ireland, WTR's management and disposal must be carried out in compliance with the Waste Management Act (1996). This stipulates that local authorities must plan for the sustainable management of all non-hazardous sludges generated in their functional area. The EU Landfill Directive (99/31/EC) has placed limits on landfill as an end disposal route for WTR, and the EU has expressed its preferred option as being recycling or reuse of the WTR. The treatment and disposal of WTR will become a more important environmental and financial issue as its production continues to increase with the development of new water treatment facilities, and as WTR quality standards become more stringent.

There is currently no specific regulatory control at community level on the application of WTR to land. The Framework Directive on Waste (91/156/EEC), which was given effect by the Waste Management Act (1996), states that the landspreading of WTR is considered as a recovery operation and, although a licence is not required, written consent from the local authority must be obtained. (One may regard such consent as constituting a licence, at law. The distinction seems to be remarkably subtle.) The application of WTR to agricultural land would, however, require a waste licence or permit and would be subject to planning and environmental considerations. Surprisingly, this option is classified as a disposal method, as the WTR would be considered a waste, rather than one deriving a beneficial use. The Environmental Protection Agency must be satisfied that waste disposal and recovery activities will not cause environmental pollution when carried out in accordance with the conditions of a waste licence.

## 3. Status of WTR in Ireland

### *3.1. Methodology of data collection*

A survey of a questionnaire by e-mail sent to nearly 200 water treatment plants (within the 29 county councils and 5 city councils across the country) was conducted in early March 2009. Pre-empting the likely issue of poor response levels from the respective water treatment plant, the questionnaire was as short and concise as possible. Hence, relatively redundant extra questions and unnecessary detail, which it was over-ambitious to expect to obtain about an adequate number of treatment plants, was of course avoided. The main objectives of the study required: (1) obtaining the quantities of WTR being produced by each water treatment plant, and (2) finding out its ultimate destination once removed from site, i.e. whether it is recycled or treated as a waste product. Therefore, the questionnaire contains these two major questions with basic information about the daily quantity of the drinking water produced and the type of coagulant being used by the plant. In addition, there is a question asking if the plant representative (responding to the survey) is aware of the potential for WTR to be recycled / reused in some way.

After the initial volley of general emails was sent out to each water treatment plant, the response rate was as low as predicted, and the subsequent investigation necessitated a vast amount of phone calls and follow-up emails. This was awkward and time consuming, and often the complete set of required data could not be obtained. Eventually every county in the country was surveyed. The response (after the phone calls and follow-up emails) ranged from 92-100% in different counties. But a deficit of information arose from the fact that some plants did not measure WTR quantities produced. Fortunately, data from all the large plants (> 70,000 $m^3$/d) were obtained as well as from a number of small plants.

### *3.2. Data analysis and creating GIS maps using ArcMap software*

Regarding the quantity of WTR, the findings indicate that a number of plants across the country record the quantities of WTR they are producing and exact figures can be obtained. Generally these are the relative large water treatment plants. The five largest water treatment plants across Ireland produce 10,944 (t-DS/yr) of WTR. But, as anticipated, many of the water treatment plants in Ireland are unaware of the quantities of WTR they are producing. There seemed to be a very definite trend; logically as the volume of water being treated increases so does the amount of sludge being produced.

As for the smaller plants, it is evident that a well defined relationship exists between volume of water and the WTR production. With this in mind, from the available data obtained a very obvious trend now becomes clear between volume of water treated and annual WTR production. This trend line may be used to ascertain estimates of annual WTR production for those counties in which no record of WTR quantities are kept but the daily production volumes of water (< 70,000 $m^3$/d) through the plant are known. The result of this correlation is as follows:

$$WTR = 0.3723Q^{0.6253} \qquad (1)$$

where $Q$ is daily volume of water production ($m^3/d$), and WTR is the annual production in tonne of dry solids. Thus, the calculated WTR production can be combined with the figures obtained accurately from the larger water treatment plants to generate the entire figure of WTR production in Ireland.

The data for annual production of WTR, coagulants used and destination of the WTR from the plants across the country were finally profiled. To illustrate the data on a county basis across the whole country, the ArcMap software was used to generate GIS maps entitled "WTR production", "coagulants" and "fate of WTR" for the geographic profile of the country.

### *3.3. Results*

#### *3.3.1. Quantity of WTR*

Prior to the presentation of WTR results, Fig. 1 illustrates the raw water source in Ireland. Over 1.8 million cubic metres of water is supplied to Irish homes and businesses daily. As can be seen from Fig. 1, most of this water, 82%, is sourced from rivers and reservoirs (surface water) and the remaining 18% is supplied from springs, groundwater and a mixture of all three. Surface water is often of varying quality and thus requiring coagulation while groundwater and spring water, is generally of a higher quality and rarely needs to be treated by coagulation.

**[INSERT FIG. 1 HERE]**

Figure 2 illustrates a GIS map of geographic distribution of the WTR production across the country. In total, WTR of 15,679 (t-DS/yr) is currently generated in Ireland. Fig. 2, using a scale running from pale yellow (representing low levels of WTR) to dark red (high levels of WTR), clearly shows that Ireland's five most populous counties, i.e. Dublin, Kildare (Dublin and Kildare constitute the Greater Dublin Regional Water Supply Area), Cork, Galway and Limerick, are producing more WTR than anywhere else in the country. The band of yellow running through the midlands indicates that a relatively small amount is being produced in these smaller counties, such as Laois and Kilkenny (based on population and industry).

**[INSERT FIG. 2 HERE]**

### *3.3.2. Coagulants used in Ireland*

Figure 3 shows the geographic distribution of the coagulants used in Ireland. It indicates a preference for alum-based coagulants. Only a few regions on the west coast and two plants in the midlands opt to use either Chemifloc101 (an alum (80%)-ferric (20%) blend) (represented by yellow) or Ferric Sulphate (represented by blue) in their plants. Ireland's five largest water treatment plants (Ballymore-Eustace, Leixlip, Tuam/Luimnaigh, Clareville (Limerick City) and Inniscara) use alum based coagulants. Overall, aluminium sulphate is the most popular choice of coagulant in the country and over 90% of WTR produced in Ireland is a result of an aluminium based coagulant.

**[INSERT FIG. 3 HERE]**

### *3.3.3. Fate of WTR*

Figure 4 presents the current situation in Ireland for disposal pathways of the WTR. It is clear that only a select few plants have their sludge removed from their facilities and reused for other purposes, amounting in total to approximately only 8% of the total WTR created on the island. Thus, 92% of WTR is being treated as a waste product: either being sent to landfills or sent down the plant's foul sewer. Of the larger plants, Tuam, Galway City and Inniscarra have the sludge removed from their facility and put to another use. At Tuam the WTR is removed by Ormonde Organics and used in composting; at Galway City the WTR produced is used by Acorn Recycling in cement kilns and at Inniscarra Acorn Recycling collect the WTR for use in quarry remediation. It should be noted that Inniscarra has supplied a quantity of WTR on two separate occasions (in 2005 and 2009) for quarry remediation; apart from these two instances the plant has disposed of its WTR in landfills.

**[INSERT FIG. 4 HERE]**

Although a few plants in County Waterford still landfill their WTR, the more common and novel choice for the final disposal pathway of the WTRs is their reuse as filter medium in constructed wetlands. Landspeading, composting, quarry remediation, use in cement manufacturing and use in constructed wetlands are the beneficial reuses in Ireland.

### *3.3.4. Awareness of WTR reuse*

One of the questions posed to Local Authorities and water treatment plants which currently treat the WTR as a waste was whether or not they were aware of the options for recycling it. There was a general lack of knowledge in this regard. In many cases, operators expressed shock, particularly among smaller plants, to realize that reuse was practicable. One typical response was the misconception that in Ireland, the law makes it unacceptable to treat WTR as anything other than a waste to be disposed of in landfills.

Among the bigger plants awareness of the possibility of reuse was certainly more common. One response showed knowledge that WTR could be used in cement manufacturing. Where awareness was prominent, our team asked about any future plans for reuse. The Leixlip plant technician had heard of a number of possibilities being explored in mainland Europe but did not know of any endeavours in Ireland towards beneficial reuse of WTR and so no efforts were being made to move to a more sustainable disposal pathway for the plant's sludge. At Inniscarra it was understood that Al-WTR could be used in cement kilns and quarry remediation but no other reuse possibility had been heard of. Although Ballymore-Eustace’s plant currently send their sludge to landfills, the plant technician was aware of the current research in UCD and efforts exploring the most beneficial reuse options for WTR. Ballymore-Eustace is now creating a new WTR treatment unit which will dewater the WTR. This will produce a more solid, more manageable WTR with less bulk.

## 4. Discussion

There is little information on quantities of WTR produced in Ireland on an annual basis. In many cases the water treatment plants themselves may not even be aware of the quantities of residual/sludge they are producing. Thus, profiling the entire water treatment setup in Ireland is the first aim of this study. Every water treatment plant in the country was surveyed to discover the quantities of the WTR produced. Where this was not known, an estimate was made based on the volume of water delivered and correlation with plants of known WTR production. But, the volume of water is not the only contributing factor to WTR production. Other matters in the treatment process including initial quality or turbidity of the source water, as well as the characteristics of the plant itself, need to be considered. Nevertheless, given the scope of the study and the time available, the volume of water being treated at the plant should give an appreciably accurate figure.

The second aim of the study is to profile the fate of WTR in Ireland by learning whether the WTR from each plant is disposed of as a waste or reused, and if reused then with which method. Since the advancements in reuse options of WTR are at a relatively early stage it is expected that many plants and plant operators will not be aware of the potential recyclable nature of the residual and will merely treat the sludge as a waste product and dump it the cheapest way available to them, most likely by landfilling or by sending it to the local sewerage plant.

From the literature, in spite of the wide range of WTR options [1], the fact is that many of these are emerging concepts, and the feasibility of some still depends on further study. It is expected that only some of these reuses are found to be in operation in Ireland. Since the country has a vast agricultural industry and many constructed wetlands sites (in total 144 sites [23]), the WTR reuses associated with agricultural land use, constructed wetlands and cement manufacturing are probably the most likely ones. They represent the authors' main recommendations for future endeavours in Ireland.

## 5. Conclusions

The results derived from this study revealed that 82% of treated drinking water in Ireland is sourced from surface water while the total WTR production in the country is 15,679 tonnes of dry solids per annum with over 90% of WTR being aluminium-salt-coagulated WTR. It was also discovered that, of this WTR quantity, approximately 8% is beneficially reused, with the other 92% being discarded as waste (most commonly by landfilling). This 8% accounts for the WTR supplied to the five different reuse methods found in Ireland, namely, composting, landspreading, cement manufacturing, constructed wetlands and quarry remediation. The authors recommend that further attempts to use WTR in constructed wetlands and cement manufacturing be made throughout Ireland and that the water treatment plants in Ireland introduce some reuses, particularly those in which WTR becomes part of the wastewater treatment.

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**Figure captions:**

Fig. 1 Raw water source in Ireland

Fig. 2 Geographic distribution of the WTR production across Ireland

Fig. 3 Geographic distribution of the coagulants used in Ireland

Fig. 4 Geographic distribution of the fate of WTR across Ireland

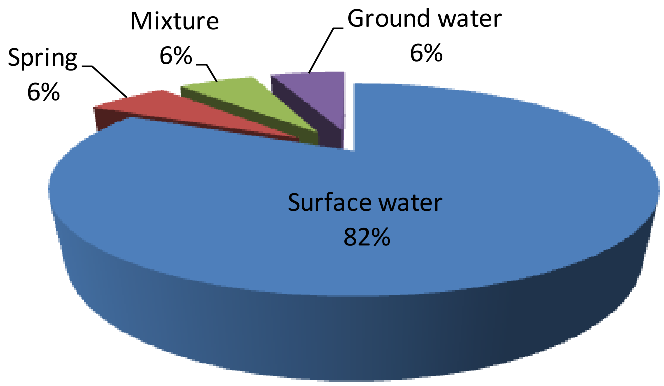


Fig. 1

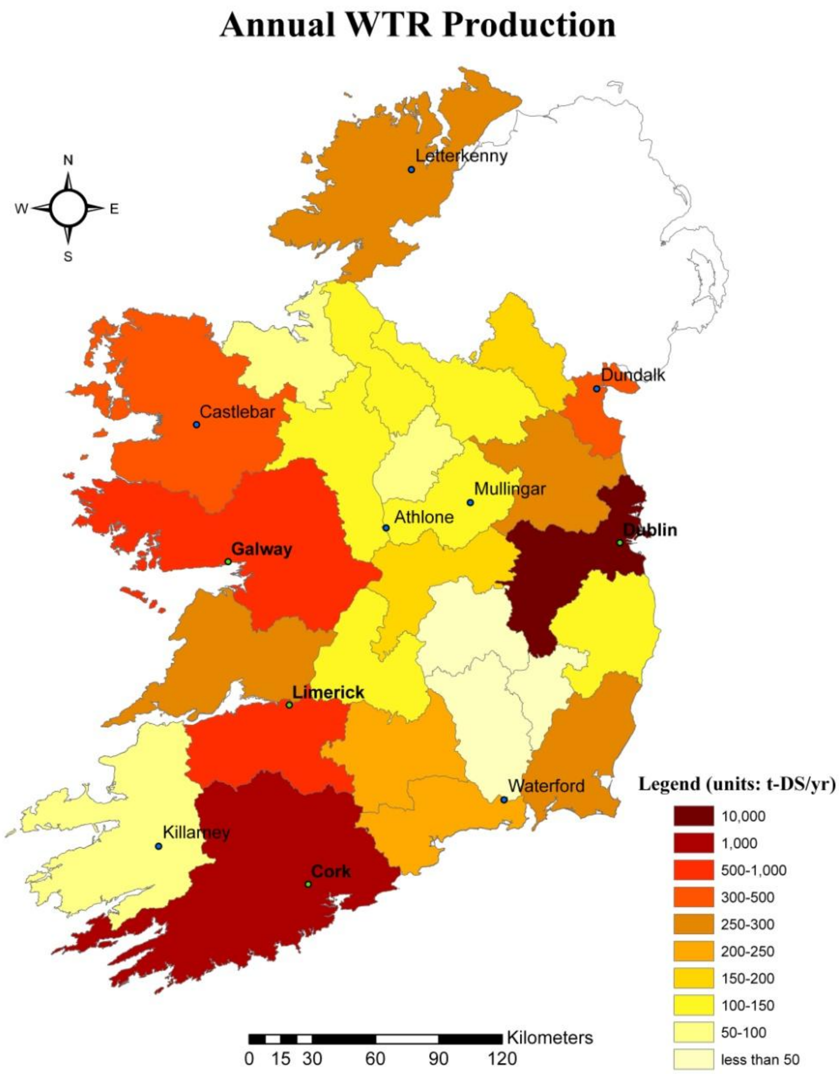
Annual WTR Production
N
W
E
S
Letterkenny
Dundalk
Castlebar
Mullingar
Athlone
Dublin
Galway
Limerick
Waterford
Killarney
Cork
Legend (units: t-DS/yr)
10,000
1,000
500-1,000
300-500
250-300
200-250
150-200
100-150
50-100
less than 50
Kilometers
0 15 30 60 90 120

Fig. 2

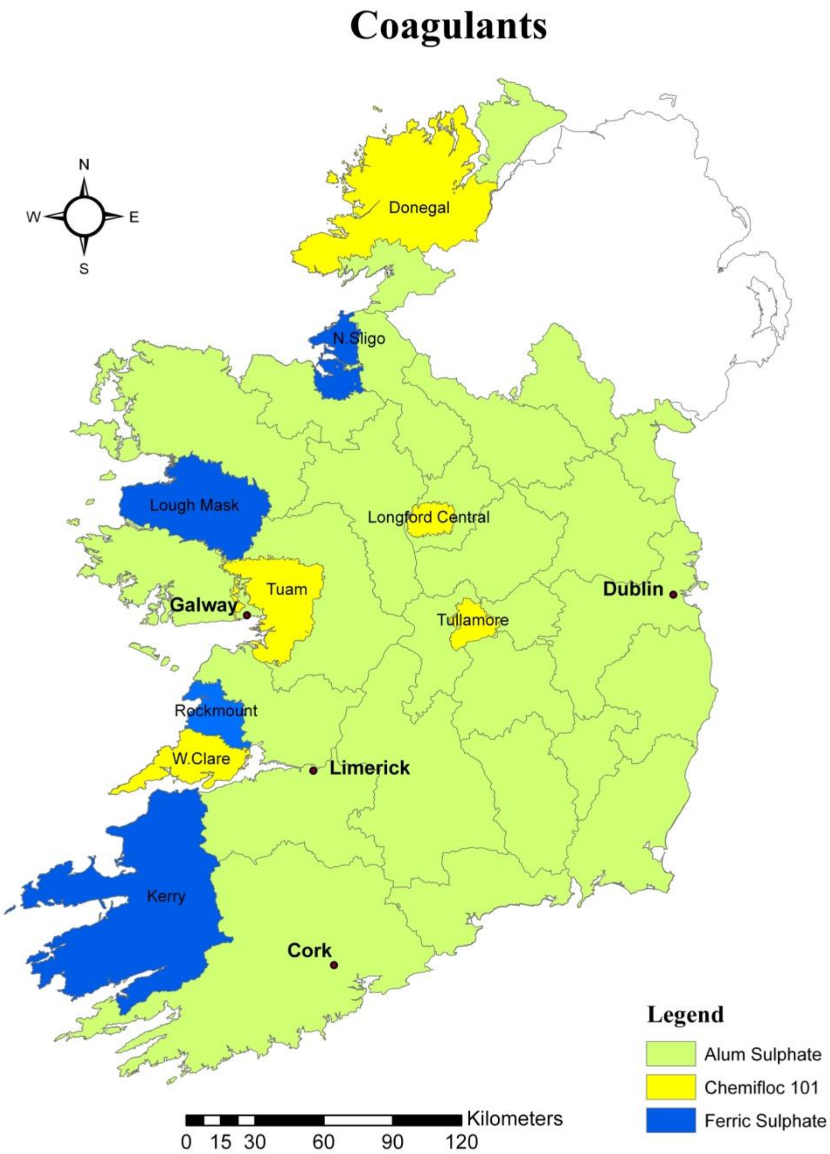
Coagulants
N
W
E
S
Donegal
N.Sligo
Lough Mask
Longford Central
Tuam
Galway
Dublin
Tullamore
Rockmount
W.Clare
Limerick
Kerry
Cork
Legend
Alum Sulphate
Chemifloc 101
Ferric Sulphate
Kilometers
0 15 30 60 90 120

Fig. 3

**Fate of WTR**

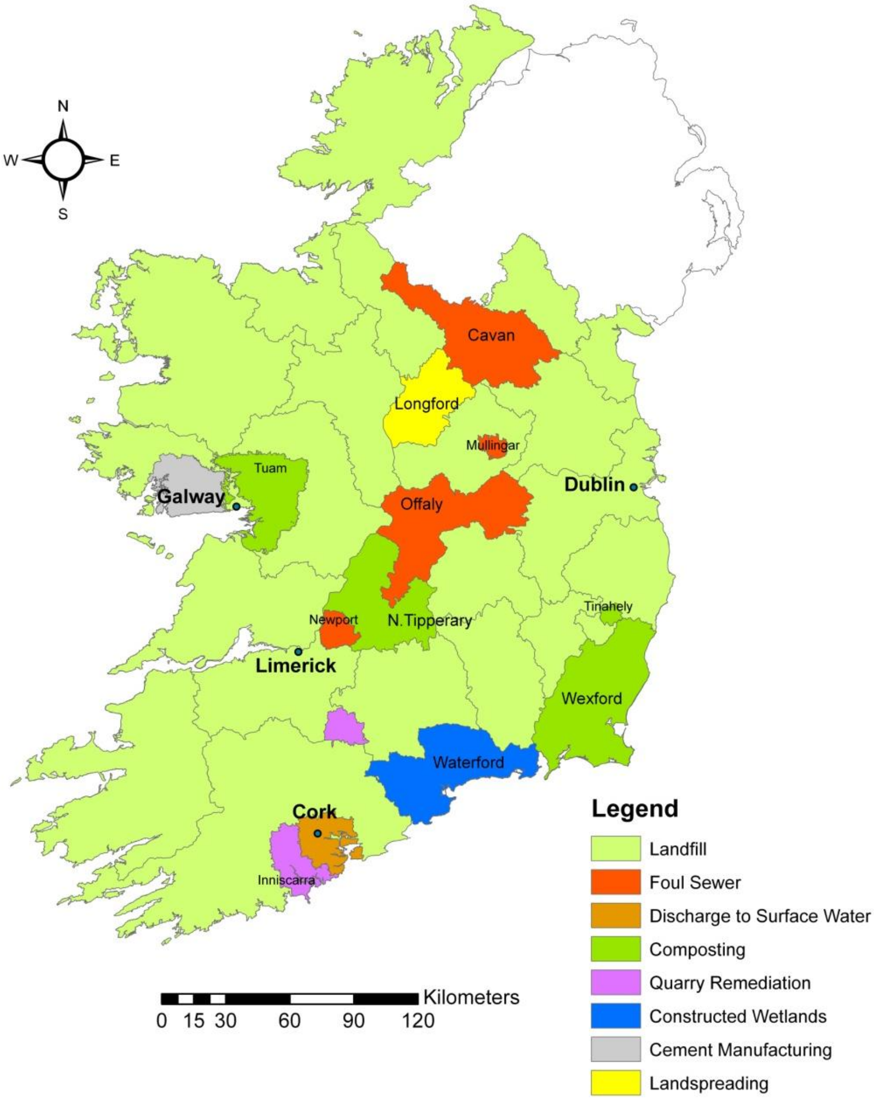


Fig. 4