Rehabilitating dryland river systemsin arid and semi-arid environments focusing on water sensitive urban design approaches

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Abstract: This research presents a review of water sensitive urban design (WSUD) approaches to rehabilitating dryland rivers, with the objective of identifying common elements to support design interventions in arid and semi-arid urban environments. Exacerbated by climate change, drought conditions have been increasing across the globe especially in arid and semi-arid regions. These conditions limit economic development, degrade the environment and adversely affect the social well-being of the citizens. Water scarcity has been identified as a key driver for future global conflicts as well as making water conservation a major focus for current research. The excessive heating driven by urban development, the water crisis and the growing effects of climate change have generated a variety of policy and planning responses. However, in some arid cities, particularly in developing countries, the severity of the issue makes these regions stand out as extreme cases in the necessary search for appropriate solutions. Rivers are part of the urban landscape, and as such play an important role in the delivery of urban ecosystem services and enhancing liveability for city dwellers. The urgent need to preserve and manage rivers and streams in these dynamically changing circumstances has led researchers to develop new or modified methods to improve the condition of urban waterways in many parts of the world. In particular, there is a significant interest in restoring rivers and streams in arid and semi-arid environments which face the unprecedented dual threats of climate change and population growth. Counter-intuitively, dryland rivers are resilient systems that can play an important role in water management in both drought or flood conditions and at the same time contribute to enhancing urban liveability. Ineffective water resource development planningfor dryland rivers causes high ecological costs to both the natural environment and cities. Rehabilitating dryland rivers in urban areas will require new water management and water sensitive urban design (WSUD) interventions. Another important aspect of WSUD is considering measures to decrease the effects of climate change on rivers that are potentially facing long-term drought conditions. In other words, WSUD provides a mechanism for retaining water in the urban landscape through rehabilitating dryland rivers while also helping to improve the condition of urban areas. The focus of this paper is on identifying suitable WSUD initiatives to reinvigorate dryland rivers in the context of urban landscape planning and management. To address the human and climatic factors affecting dryland rivers, both long-term and short-term WSUD solutions must be considered. This paper adopts a staged approach to this challenge; first the condition of dryland rivers in arid and semi-arid regions is investigated, based on the literature. Particular attention is given to urban (and urbanising) locations in developing countries. Drawing on both academic and ‘grey’ literature (such as government and NGO reports) some of the key outcomes from WSUD revitalisation efforts and research projects focused on dryland rivers in arid and semi-arid regions are presented. Based on analysis of the lessons from the above review of theory and practice, a set of key WSUD principles relevant to the rehabilitation of urban dryland riversis introduced. The intent is to test these principles in practice through application to case studies in a subsequent stage of this research.

Key words: Arid cities; Dryland rivers; Water crisis; WSUD

Introduction

The provision of a secure water supply is a challenging task for governments globally, particularly in the context of growing urbanisation. Water scarcity has been identified as a key driver for future global conflicts as well as making water conservation a major focus for current research (Ahuja 2016). These conditions limit economic development, degrade the environment and adversely affect the social well-being of the citizens (Ward and Pulido-Velazquez 2008). Urbanisation combined with climate change has a negative impact on groundwater recharge, water supplies, the qualitative and quantitative state of receiving rivers, and urban climate (MacDonald, Calow et al. 2009). Clearly, there is a need for more effective solutions for managing urban water (Howe and Mitchell 2011). Exacerbated by climate change, drought conditions have been increasing across the globe especially in arid and semi-arid regions (Allan 1992). It is becoming increasingly clear that these regions of the world have encountered a stage of severe water scarcity (Kahil, Dinar et al. 2015). The severity of the issue in semi-arid cities in developing countries makes these regions stand out as extreme cases in the necessary search for appropriate solutions (Zyoud, Kaufmann et al. 2016).

Water resource management is one of the greatest global challenges of the present century which can be tackled in different ways (Donofrio, Kuhn et al. 2009). Most studies have concentrated on improved planning, design, and management of urban water in developed countries such as Germany, the USA with 'low-impact development', the UK with their 'sustainable urban drainage system', New Zealand with 'low impact urban design and development' and Australia with 'water sensitive urban design' (WSUD) (Ashley, Shucksmith et al. 2013). While these studies can be good examples to review the methods in which water sensitive planning and design are considered globally, there is a need for more research to explore innovative approaches in arid and semi-arid regions (Brown, Keath et al. 2009). WSUD provides a mechanism for retaining water in the urban landscape through stormwater harvesting and reuse (Wong, 2006). Accordingly, as WSUD provides one of the key approaches to resolving these dilemmas, it should be implemented strategically into the urban landscape (Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2013). The common denominator of most WSUD related research and practice is that they reflect the experiences of developed countries rather than those of less developed countries such as in the Middle East (Zyoud et al., 2016).

These issues have recently been gaining greater global attention. Rivers are part of the urban landscape, and as such play an important role in the delivery of urban ecosystem services and enhancing liveability for city dwellers. It is widely recognised that many rivers have been severely affected by intensive human impacts. This has led to the implementation of hundreds of river rehabilitation projects globally (Cottington 2005).This need to preserve and manage rivers and streams in these climate condition has made researchers develop new or modified methods to make improvements in the condition of urban waterways in many parts of the world (Thoms and Sheldon 2002). Rivers in arid / semi-arid areas (dryland rivers) are resilient systems that can play an important role in water management in both drought or flood conditions and at the same time contribute to enhancing urban liveability (Petts 2017). Ineffective water management planning for dryland rivers can lead to high ecological costs to both the natural environment and cities. Many different methods have been applied to decrease the effects of climate change and human activity on water scarcity, but these are not directly adaptable to the conservation and rehabilitation of dryland rivers compared to other elements of urban landscape. Rehabilitating dryland rivers in urban areas will require new water management and water sensitive urban design (WSUD) interventions (Yirdaw, Tigabu et al. 2017).

Thus, in this paper, the condition of dryland rivers in arid and semi-arid regions is investigated. Then, it describes some of the key findings gained from rehabilitation experiments and research projects conducted on dryland rivers in temperate and arid regions. The lessons learnt are then analysed to present WSUD principles for dryland river rehabilitation in the context of arid and semi-arid climates. This paper helps to implement and/or evaluate dryland river rehabilitation water management techniques within the context of each case in semi-arid regions.

Materials and Methods

Over the next 30 years, over 60% of the world population will live in urban areas. This rapid growth in population is expected to be even more evident in developing countries (Bernhardt and Palmer 2007). The ecological and environmental impacts of this phenomenonwill need a global response to. Urbanisation affects local climate, air pollution, water use, and consumption of natural resources to produce energy (Dudgeon, Arthington et al. 2006). Due to population growth, poor irrigation systems, the lack of water storage techniques and management issues, the severity of the problem in arid and semi-arid regions is huge and these regions are faced with disastrous consequences of water scarcity such as land degradation, declining standard of living, etc (Martin-Carrasco, Garrote et al. 2013, Karandish, Salari et al. 2015). Therefore, the long-term water management of arid and semi-arid regions requires an informed management framework to ensure water across all urban sectors. Climate change and uncontrolled use of water for irrigated agriculture and other human needs have resulted in increasing the occurrence, duration, and frequency of river drying (Döll and Schmied 2012). Dryland rivers are particularly endangered natural systems because of inadequate management practices and policies. Even in developed countries such as the USA and Europe, dryland rivers are inadequately protected (Leibowitz, Wigington et al. 2008). The increasing interest in dryland rivers research should support and provide critical advances in knowledge and improvements in integrated water managementand at the same time define the importance of these rivers for urban liveability (Buurman and Padawangi 2017).

Within the context of a broader research project focused on planning and design to support dryland river rehabilitation, the main purpose of this review is to provide a general overview of rehabilitation research in dryland rivers, to emphasise the important role of these elements in urban water management, to define the context for findings that emerge from recent international research in the dryland rivers, and to identify gaps that may shape the priorities in future research efforts in arid and semi-arid regions.

Water scarcity in semi-arid regions

Drought is a climate condition that is followed by temporary water shortages, over a period of time – a season, a year, or several years. The differences are in duration, intensity and extent (Buurman, Mens et al. 2017). Water scarcity is a result of drought conditions which lead to restrictions on consumption and occurs when demand exceeds the available resources. Currently, most of the Mediterranean countries are facing water scarcity (Liu, Yang et al. 2017). In arid and semi-arid areas drought results from various factors, including climatic variations and human activities (Abu-Allaban, El-Naqa et al. 2015).

Although drought is considered an unusual event, it is a normal climate condition and it is different from aridity, which is a permanent state in low rainfall areas (Blaikie 2016, Hanna and Oliva 2016). However, in this paper, a combination of both drought and aridity is considered to define arid and semi-arid regions' climate. Arid and semi-arid regions are areas with long term or permanent drought conditions which result in water scarcity. It is obvious that some parts of the world are encountering a stage of water crisis in which climate change exacerbates existing conditions. In semi-arid regions, water scarcity can lead to loss of livelihood, forced migrations and open conflict (Kahil, Dinar et al. 2015). Especially in developing countries in arid areas, if nothing has changed to manage water shortages, most of these countries will face fundamental issues in providing freshwater and will lose urban life (Hanna and Oliva 2016). With heavy water demand, population growth and the unprecedented effects of climate change, there is a need to establish water management strategies in those regions where water scarcity is a growing issue.

Rivers and dryland rivers

Dryland for many years, most research focused on perennial rivers (Adams 2014). This paper reviews some factors which help to define dryland rivers. Based on this review, dryland rivers may be defined as belonging to areas which have long term or permanent drought or refer to all temporary, ephemeral, seasonal, and episodic streams and rivers in defined channels. Research on intermittent rivers or dryland rivers has a short history. These rivers constitute more than 30% of the length of the global river network and the proportion is growing as a result of climate change, urbanisation, and water usage and degradation (Datry, Larned et al. 2014). For example, in Australia, United States, Greece, and South Africa more than half of the total length of rivers are intermittent. In Canada many rivers are considered as intermittent, so too in Alpine, Arctic, and Antarctic areas. Therefore, there is a significant increase in the growth of intermittent river numbers worldwide (Leigh, Boulton et al. 2016).

Additionally, with increasing human impact on water resources, sections of some perennial rivers have become intermittent in the last 50 years, including large rivers such as the Nile, Indus, Yellow, Amu and Syr Darya, Rio Grande, and Colorado (Datry, Larned et al. 2014). In arid and semi-arid regions the speed of change is greater than in other parts of the world, such that most of the once-perennial rivers in these regions are now intermittent (Yao, Zheng et al. 2015). In the near future, this process is expected to intensify in these regions, leading to potential water crises (Döll and Schmied 2012).

The difference between conventional rivers and dryland rivers refers to high flow variability. Dryland rivers are important resources; both water quality and quantity may be improved through regulation to enable integrated surface water management. Although dryland rivers are becoming a major subject for research ,there are still gaps relating to dryland river rehabilitation that need to be addressed (White and Stromberg 2011). Recent research in arid central Australia shows a drastic change in the condition of dryland rivers which makes the need for more research crucial. Moreover, as a result of climate change dryland rivers are facing extreme temporal and spatial variability of rainfall, surface run off and sediment transport, and lack of integration between tributary and trunk channels. Research in central Australia illustrates that to establish a framework for rehabilitating dryland rivers, studies on rivers which have been rehabilitated can offer guidance (Kingsford, Bino et al. 2017).

The major deficiencies in dryland river research relate to three main areas (Mwenzwa 2017):

1- Limited study of some aspects of dryland rivers such as characteristics of floodplain, planting effects, downstream changes.
2- Ignoring the scale of the changes in the area.
3- Considering approaches for long-term and short-term management based on the dryland river behaviour and condition.

A key to reaching a reasonable outcome is considering the past and present conditions of the area. This will also help develop a theoretical basis for the assessment of future developments in dryland river systems which will contribute to improved scientific understanding and environmentally sensitive management (Yirdaw, Tigabu et al. 2017).

Water sensitive urban design and dryland rivers rehabilitation

Rehabilitation is defined as remedial activities that are used in dryland rivers while not necessarily going back to the 'pre-disturbance' conditions. River rehabilitation increases the resiliency of local communities and ecosystems (Bernhardt and Palmer 2007). According to the extreme climate condition of arid regions and because of a limitation in water accessibility, the rehabilitation of dryland rivers in these regions is more challenging and time consuming than in humid sites. Determining the extent and approach required to restore a dryland river is not particularly difficult (Glenn, Nagler et al. 2017). However, experience and research on dryland rehabilitation at the landscape scale are much less common (Dorrough and Moxham 2005). Additionally, there is less experience in arid regions than in humid areas, but some studies are available from South America (Cantarello, Newton et al. 2011) from Africa and Asia (Heshmati and Squires 2013), and the Mediterranean region (Mayor, Bautista et al. 2009). Translation of this knowledge to arid regions is complicated, because of the difference in extent and frequency of fluvial events. Human impact to control flow makes dryland rivers more vulnerable and the research is more complicated. To address the issues of rehabilitating dryland rivers and reach a reasonable restoration framework, a comprehensive understanding of the landscape processes in both natural and social aspects is required. Moreover, effective measures depend on an understanding of the interactions between surface water and groundwater (Svejcar and Kildisheva 2017).

Water resource management is one of the greatest global challenges of the present century which can be tackled in different ways (Donofrio, Kuhn et al. 2009). Water sensitive urban design (WSUD) provides a mechanism for retaining water in the urban landscape through storm water harvesting and reuse (Wong 2006). Accordingly, as WSUD provides one of the key approaches to resolving these dilemmas, it should be implemented strategically into the urban landscape (Coutts, Tapper et al. 2013). The common denominator of most WSUD related research and practice is that they reflect the experiences of developed countries rather than those of less developed countries such as in the Middle East (Biswas 1991). Most studies have concentrated on improved planning, design, and management of urban water in developed countries such as Germany, the USA with 'low-impact development', the UK with their 'sustainable urban drainage system', New Zealand with 'low impact urban design and development' and Australia with 'water sensitive urban design' (Morison and Brown 2011, Ashley, Shucksmith et al. 2013). While these studies can be good examples to review the methods in which water sensitive planning and design are considered globally, there is a need for more research to explore innovative approaches in arid and semi-arid regions (Brown, Keath et al. 2009). The experiences of developing countries are often based on traditional vernacular approaches to water management (Ezeabasili, Okoro et al. 2014), which should be factored into place-specific planning and design responses. The overall goal of such an integrated approach is that arid and semi-arid areas should be able to protect themselves against the possibility of drought scenarios and still succeed in sustaining the environment, the economy and the population (Lottering, Du Plessis et al. 2015).

In this research, water sensitive urban design is a series of principles that are adopted to the site of a dryland river to maximise the use of the increased run-off generated by urbanisation and ameliorate the condition of these systems in urban areas. However, it is worth mentioning that the techniques and WSUD principles for dryland river rehabilitation will be introduced through future research.

To achieve water sensitivity each urban element plays a role. Dryland rivers are parts of the urban landscape that should be considered in the ecologically sustainable development of a city. Ecologically sustainable development objectives can be achieved by considering three interrelated components. The first component is integrated water cycle management which extends to catchment/regional scale and includes long term water resource management and planning. This component considers that waste water comes from three main sources: potable water (that is, safe to drink or to use for food preparation), storm water (that is, the water draining off a site from the rain that falls on the roof and land, and everything it carries with it, and waste water (that is any water that has been affected by human use or water used in any combination of domestic, industrial, commercial or agricultural activities). By integrating waste water coming from these sources in dryland rivers rehabilitation principles, arid and semi-arid areas can obtainan appropriate source of water for urban use. The second component is related to the urban design and built form of the urban landscape in which dryland rivers are located. Locations, which concentrate on the composition of patterns of built form with their own core and periphery. To make this happen involves the integration of eight factors: urban planning, pedestrian movement, traffic management and road design, recreation and open space management, human comfort and microclimate, sense of place and identity, response to climate and topography, response to socioeconomic factors. The third component is associated with water sensitive urban design (WSUD) which focuses on strategies to capture, control and recycle waste water in an efficient way. This component requires there to be a mutually beneficial relationship between integrated water cycle management and rehabilitation strategies in dryland rivers. This approach provides an opportunity to collect waste water forreuse in cities. In this way, cities will be sure that they can achieve ecologically sustainable objectives related to water sensitivity of a dryland river in the long term by considering the three components of these framework simultaneously (figure 1). In this regard, based on the eight above elements, a model to understand the dryland river system in relation to the built form of the city will be introduced and expanded followed by this research in the future.

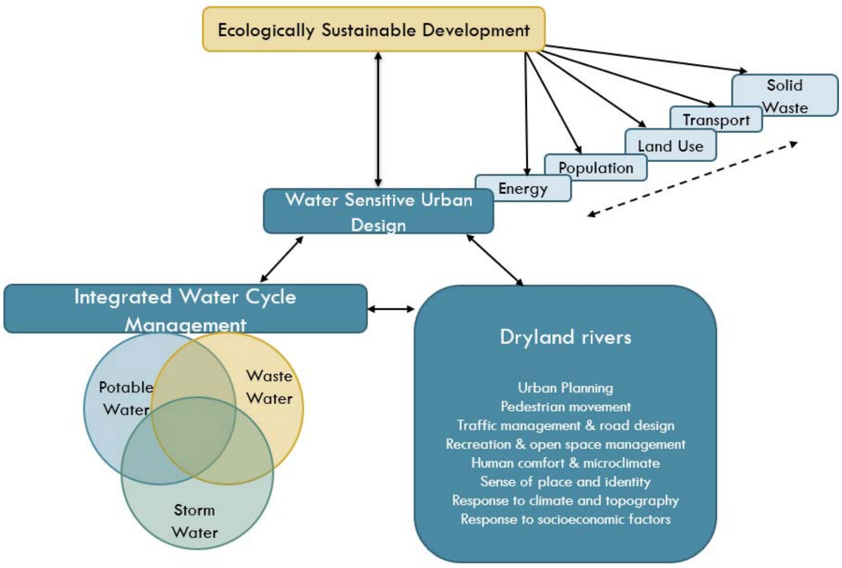

Figure 1. Water sensitive urban design and sustainable development (Adapted from(Ashley, Lundy et al. 2013))

Discussion: Key findings in the process of rehabilitation

A majority of dryland river rehabilitation projects around the world can belisted in one of two categories (Bernhardt and Palmer 2007, Datry, Larned et al. 2014, Buurman and Padawangi 2017, Glenn, Nagler et al. 2017, Svejcar and Kildisheva 2017):

a. Stormwater management

In urban areas, surface water run-off passes through pipes to water retaining structures. These structures were constructed to collect water and move it away from the landscape to decrease the risk of flooding. Today, beside the aim of reducing peak stream flow, there are efforts to maximise the use of surface water in urban areas and improve the quality of the water. Many site-specific monitoring efforts have been undertaken to examine the effect of stormwater management (SWM) installations on peak flows as well as pollutant loads (Xu, Chen et al. 2016). Most of these water management practices which are used in different countries integrate stormwater into the landscape by techniques such as bioretention systems, swales, ponds, rain gardens, etc (Wong 2000). When there is a need for greater treatment, a combination of techniques- such as small ponds- should be used instead of a large stormwater facility. Through these techniques, stormwater enters a quantity-control structure, usually a dry detention pond, after passing through a series of water management structures (figure 2a). For improving the quality and erosion control a combination of these structures should be applied. Although there are many techniques to manage water in these areas, there is still a need for more research to find out whether these approaches have positive impacts (Yirdaw, Tigabu et al. 2017). In addition, the impact of water management techniques on adjacent ecosystems requires more research and experiment.

b. Bank stabilisation

There are some techniques to decrease the risk of erosion in dryland rivers. Re-grading the streambank, use of bio-engineered products such as coconut fibre rolls, and installing engineered structures such as constructed wetlands are some of these approaches (Bainbridge 2012). Planting vegetation and use of rootwads and boulder revetments can also be considered in the bank stabilisation. It should be considered that these techniques in rural and agricultural areas can achieve more satisfying results compared to urban areas, where the techniques must cope with high storm flow because of the impervious paving and surrounding infrastructure (Bainbridge 2012). Bank stabilisation is followed by channel reconfiguration and grade control, and riparian replanting and management. These two techniques increase the stability of the river bank by improving water conveyance especially in high flow areas. Planting the area not only it improves the river bank, but also enhances biodiversity in the area. However, in most cases, exotic plants should be removed before replanting the area (Abernethy and Rutherfurd 2000, Allan and Castillo 2007) (figure 2b).

Figure 2. stormwater pond, USA (mucksuckers.com)

Figure 2b. bank stabilisation using coir logs, Australia (aussieenvironmental.com.au)

Based on what is reviewed and the experience of other countries, some key principles can be identified:

- The first step in the rehabilitation of a degraded dryland river should be identifying and addressing the multiple factors that lead to degradation; understanding these factors is essential to developing an appropriate rehabilitation strategy (Bestelmeyer, Okin et al. 2015). In general, a successful rehabilitation strategy for dryland rivers addresses the intensity, duration, frequency, and the diversity and scale of planted areas. However, in cases of severe degradation and reaching a quite steady state, rehabilitation may not be achieved (White and Stromberg 2011).
- Based on the feature of each section of a dryland river like streambank seepage and groundwater flow, type, density, and scale of vegetation, the study area should be divided into three zones: streambank, riparian, and floodplain (Figure 3). Each of these parts should be analysed based on planting, soil, location, and slope to be addressed by WSUD principles (McDonald, Sheng et al. 2013).

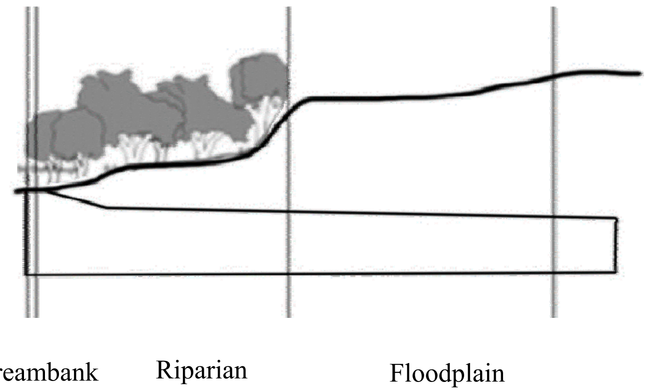

Figure 3. Sections of dryland river (Adapted from (McDonald, Sheng et al. 2013))

- Although most projects on dryland rehabilitation have focused on a specific site or scale, environmental factors and processes which include soils, climate, topography, hydrology, land management, water management, and ecological systems should be considered at much larger scales (Cost Action 2016). Thus, planning at the landscape scale is more relevant to the rehabilitation of degraded drylands, where the multiple functions of the different adjoining uses are considered. In addition, it is more logical to count on measures for rehabilitation and livelihood of a dryland river at landscape-level than at a micro site scale (Yirdaw, Tigabu et al. 2017)
- Because of the price of land in urban areas and also the existence of infrastructure, urban rehabilitation projects are more expensive compared to rural areas (Bernhardt and Palmer 2007). The restoration of dryland rivers in cities is interlinked with local needs, urban development planning and design, grey and green infrastructure planning, open space network planning, political and economic pressures. The lack of experience of technical knowledge in translating rehabilitation techniques from research into practice and also from one context into another can also be a limitation (Niezgoda and Johnson 2005). Also, existing infrastructure should be considered during the process of applying techniques for rehabilitation as they might have impacts on the failure or success of the project (Jansson, Backx et al. 2005).
- From the water quality point of view, surface runoff contains heavy metals that are collected from parking areas, herbicides, and other nutrients which should also be treatedin the process of rehabilitation (Dusa, Timothy et al. 2017).

Conclusion

Responding properly to the threat of climate change especially in drought prone regions requires developing research relevant to all the factors that are related to this threat. Land degradation is a serious and increasing threat that has its drastic impacts on people's lives globally. The increasing prevalence of dryland rivers isdriven by human activities adverse climatic conditions (such as recurrent droughts) and population increase (Petts 2017). Thus, the need for urgent remedial actions to rehabilitate these systems is undeniable. Although this may cost a lot for governments, there is a general understanding that the cost of rehabilitation and sustainable management of dryland rivers is lower than the losses that would be generated if dryland river rehabilitation is not achieved (Yirdaw, Tigabu et al. 2017).

Thus, throughout the present study, key concepts related to the rehabilitation of dryland rivers in arid and semi-arid regions through water sensitive urban design approaches are presented. However, because of the relatively young history of this practice (four decades), there is a lack of strong relation between research and practice (Menz, Dixon et al. 2013, Palazzo 2018). Thus, to achieve optimal outcomes, there should be a correlation between empirically and practically based rationale which leads to the improvement in both theory and practice of rehabilitating dryland rivers. Most restoration efforts have focused on the research scale. Thus, presenting a landscape-level multidisciplinary approach, would increase the likelihood of addressing environmental and societal needs (Wohl 2017).

Above all, there should be an integration between local and regional communities and consideration of their needs; clarifying the benefits and costs of planning could raise the chance of success. This review identifies an urgent need to restore dryland rivers especially in arid and semi- arid environments that are coping with the water crisis (McDonald, Sheng et al. 2013). However, this paper emphasises that, this is just a start for future projects on different aspects of applying WSUD techniques to restoring these areas. In other words, the outcome of this article could be considered as a direction for future research to present WSUD framework for dryland rivers.

References:

[1] Abernethy, B. and I. D. Rutherfurd (2000). "The effect of riparian tree roots on the mass-stability of riverbanks." Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group 25(9): 921-937.
[2] Abu-Allaban, M., A. El-Naqa, M. Jaber and N. Hammouri (2015). "Water scarcity impact of climate change in semi-arid regions: a case study in Mujib basin, Jordan." Arabian Journal of Geosciences 8(2): 951-959.
[3] Adams, W. M. A. (2014). Wasting the Rain (Routledge Revivals): Rivers, People and Planning in Africa, Routledge.
[4] Ahuja, S. (2016). Chemistry and Water: The Science Behind Sustaining the World's Most Crucial Resource, Elsevier.
[5] Allan, J. (1992). "Substitutes for water are being found in the Middle East and North Africa." GeoJournal 28(3): 375-385.
[6] Allan, J. D. and M. M. Castillo (2007). Stream ecology: structure and function of running waters, Springer Science & Business Media.
[7] Ashley, R., L. Lundy, S. Ward, P. Shaffer, A. Walker, C. Morgan, A. Saul, T. Wong and S. Moore (2013). Water-sensitive urban design: opportunities for the UK. Proceedings of the Institution of Civil Engineers: Municipal Engineer, ICE Publishing.
[8] Ashley, R., J. Shucksmith, J. Blanksby, L. Sharp, S. Tait, P. Shaffer and J.-M. Stam (2013). "Water sensitive urban design in a European context." Water Sensitive Urban Design 2013: WSUD 2013: 209.
[9] Bainbridge, D. A. (2012). A guide for desert and dryland restoration: new hope for arid lands, Island Press.
[10] Bernhardt, E. S. and M. A. Palmer (2007). "Restoring streams in an urbanizing world." Freshwater Biology 52(4): 738-751.
[11] Bestelmeyer, B. T., G. S. Okin, M. C. Duniway, S. R. Archer, N. F. Sayre, J. C. Williamson and J. E. Herrick (2015). "Desertification, land use, and the transformation of global drylands." Frontiers in Ecology and the Environment 13(1): 28-36.
[12] Biswas, A. K. (1991). "Water for sustainable development in the 21st century: a global perspective." International Journal of Water Resources Development 7(4): 219-224.
[13] Blaikie, P. (2016). The political economy of soil erosion in developing countries, Routledge.
[14] Brown, R. R., N. Keath and T. Wong (2009). "Urban water management in cities: historical, current and future regimes." Water science and technology 59(5): 847-855.
[15] Buurman, J., M. J. Mens and R. J. Dahm (2017). "Strategies for urban drought risk management: a comparison of 10 large cities." International journal of water resources development 33(1): 31-50.
[16] Buurman, J. and R. Padawangi (2017). "Bringing people closer to water: integrating water management and urban infrastructure." Journal of Environmental Planning and Management: 1-18.
[17] Cantarello, E., A. C. Newton, R. A. Hill, N. Tejedor-Garavito, G. Williams-Linera, F. López-Barrera, R. H. Manson and D. J. Golicher (2011). "Simulating the potential for ecological restoration of dryland forests in Mexico under different disturbance regimes." Ecological Modelling 222(5): 1112-1128.
[18] Cottington, P. (2005). Recent lessons on river rehabilitation in eastern Australia, Cooperative Centre for Freshwater Ecology.

[19] Coutts, A. M., N. J. Tapper, J. Beringer, M. Loughnan and M. Demuzere (2013). "Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context." Progress in Physical Geography 37(1): 2-28.
[20] Datry, T., S. T. Larned and K. Tockner (2014). "Intermittent rivers: a challenge for freshwater ecology." BioScience 64(3): 229-235.
[21] Döll, P. and H. M. Schmied (2012). "How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis." Environmental Research Letters 7(1): 014037.
[22] Donofrio, J., Y. Kuhn, K. McWalter and M. Winsor (2009). "Water-sensitive urban design: An emerging model in sustainable design and comprehensive water-cycle management." Environmental Practice 11(3): 179-189.
[23] Dorrough, J. and C. Moxham (2005). "Eucalypt establishment in agricultural landscapes and implications for landscape-scale restoration." Biological Conservation 123(1): 55-66.
[24] Dudgeon, D., A. H. Arthington, M. O. Gessner, Z.-I. Kawabata, D. J. Knowler, C. Lévêque, R. J. Naiman, A.-H. Prieur-Richard, D. Soto and M. L. Stiassny (2006). "Freshwater biodiversity: importance, threats, status and conservation challenges." Biological reviews 81(2): 163-182.
[25] Dusa, A. A., N. Timothy, S. Magili and S. Tukur (2017). "Determination of Heavy Metals in Boreholes, Hand Dug Wells and Surface Water in some Selected Areas of Mubi North Local Government Area Adamawa State, Nigeria." International Research Journal of Chemistry and Chemical Sciences 4(1): 075-081.
[26] Ezeabasili, A., B. Okoro and A. Ezeabasili (2014). "Water resources: management and strategies in Nigeria." AFRREV STECH: An International Journal of Science and Technology 3(1): 35-54.
[27] Glenn, E. P., P. L. Nagler, P. B. Shafroth and C. J. Jarchow (2017). "Effectiveness of environmental flows for riparian restoration in arid regions: A tale of four rivers." Ecological Engineering 106: 695-703.
[28] Hanna, R. and P. Oliva (2016). "Implications of climate change for children in developing countries." The Future of Children: 115-132.
[29] Heshmati, G. A. and V. Squires (2013). Combating desertification in asia, africa and the Middle East, Springer.
[30] Howe, C. and C. Mitchell (2011). Water sensitive cities, IWA Publishing.
[31] Jansson, R., H. Backx, A. Boulton, M. Dixon, D. Dudgeon, F. Hughes, K. Nakamura, E. Stanley and K. Tockner (2005). "Stating mechanisms and refining criteria for ecologically successful river restoration: a comment on Palmer et al.(2005)." Journal of Applied Ecology 42(2): 218-222.
[32] Kahil, M. T., A. Dinar and J. Albiac (2015). "Modeling water scarcity and droughts for policy adaptation to climate change in arid and semiarid regions." Journal of Hydrology 522: 95-109.
[33] Karandish, F., S. Salari and A. Darzi-Naftchali (2015). "Application of virtual water trade to evaluate cropping pattern in arid regions." Water resources management 29(11): 4061-4074.
[34] Kingsford, R. T., G. Bino and J. L. Porter (2017). "Continental impacts of water development on waterbirds, contrasting two Australian river basins: Global implications for sustainable water use." Global change biology 23(11): 4958-4969.
[35] Leibowitz, S. G., P. J. Wigington, M. C. Rains and D. M. Downing (2008). "Non-navigable streams and adjacent wetlands: addressing science needs following the Supreme Court's Rapanos decision." Frontiers in Ecology and the Environment 6(7): 364-371.
[36] Leigh, C., A. J. Boulton, J. L. Courtwright, K. Fritz, C. L. May, R. H. Walker and T. Datry (2016). "Ecological research and management of intermittent rivers: an historical review and future directions." Freshwater Biology 61(8): 1181-1199.
[37] Liu, J., H. Yang, S. N. Gosling, M. Kummu, M. Flörke, S. Pfister, N. Hanasaki, Y. Wada, X. Zhang and C. Zheng (2017). "Water scarcity assessments in the past, present, and future." Earth's Future 5(6): 545-559.
[38] Lottering, N., D. Du Plessis and R. Donaldson (2015). "Coping with drought: the experience of water sensitive urban design (WSUD) in the George Municipality." Water SA 41(1): 1-8.
[39] MacDonald, A. M., R. C. Calow, D. M. Macdonald, W. G. Darling and B. E. Dochartaigh (2009). "What impact will climate change have on rural groundwater supplies in Africa?" Hydrological Sciences Journal 54(4): 690-703.
[40] Martin-Carrasco, F., L. Garrote, A. Iglesias and L. Mediero (2013). "Diagnosing causes of water scarcity in complex water resources systems and identifying risk management actions." Water resources management 27(6): 1693-1705.
[41] Mayor, Á. G., S. Bautista and J. Bellot (2009). "Factors and interactions controlling infiltration, runoff, and soil loss at the microscale in a patchy Mediterranean semiarid landscape." Earth Surface Processes and Landforms 34(12): 1702-1711.
[42] McDonald, A. K., Z. Sheng, C. R. Hart and B. P. Wilcox (2013). "Studies of a regulated dryland river: surface–groundwater interactions." Hydrological Processes 27(12): 1819-1828.
[43] Menz, M. H., K. W. Dixon and R. J. Hobbs (2013). "Hurdles and opportunities for landscape-scale restoration." Science 339(6119): 526-527.

[44] Morison, P. J. and R. R. Brown (2011). "Understanding the nature of publics and local policy commitment to Water Sensitive Urban Design." Landscape and urban planning 99(2): 83-92.
[45] Mwenzwa, E. M. (2017). "A Public-Private Partnership Scheme To Avert Desertification in the Drylands of Kenya: Lessons for Social Scientists." Journal of the Geographical Association of Tanzania 36(1).
[46] Niezgoda, S. L. and P. A. Johnson (2005). "Improving the urban stream restoration effort: identifying critical form and processes relationships." Environmental management 35(5): 579-592.
[47] Palazzo, E. (2018). "From water sensitive to floodable: defining adaptive urban design for water resilient cities." Journal of Urban Design: 1-21.
[48] Petts, G. (2017). "Perspective: river science for dryland river regulation." Transactions of the Royal Society of South Australia 141(2): 230-236.
[49] Svejcar, L. N. and O. A. Kildisheva (2017). "The age of restoration: challenges presented by dryland systems." Plant Ecology 218(1): 1-6.
[50] Thoms, M. and F. Sheldon (2002). "An ecosystem approach for determining environmental water allocations in Australian dryland river systems: the role of geomorphology." Geomorphology 47(2-4): 153-168.
[51] Ward, F. A. and M. Pulido-Velazquez (2008). "Water conservation in irrigation can increase water use." Proceedings of the National Academy of Sciences: pnas. 0805554105.
[52] White, J. M. and J. C. Stromberg (2011). "Resilience, restoration, and riparian ecosystems: case study of a dryland, urban river." Restoration Ecology 19(1): 101-111.
[53] Wohl, E. (2017). "Connectivity in rivers." Progress in Physical Geography 41(3): 345-362.
[54] Wong, T. (2000). "Improving urban stormwater quality-from theory to implementation." Journal of the Australian Water Association, 27(6): 28-31.
[55] Wong, T. H. (2006). "An overview of water sensitive urban design practices in Australia." Water Practice and Technology 1(1): wpt2006018.
[56] Xu, H., L. Chen, B. Zhao, Q. Zhang and Y. Cai (2016). "Green stormwater infrastructure eco-planning and development on the regional scale: a case study of Shanghai Lingang New City, East China." Frontiers of Earth Science 10(2): 366-377.
[57] Yao, Y., C. Zheng, J. Liu, G. Cao, H. Xiao, H. Li and W. Li (2015). "Conceptual and numerical models for groundwater flow in an arid inland river basin." Hydrological Processes 29(6): 1480-1492.
[58] Yirdaw, E., M. Tigabu and A. A. Monge Monge (2017). "Rehabilitation of degraded dryland ecosystems–review." Silva Fennica.
[59] Zyoud, S. H., L. G. Kaufmann, H. Shaheen, S. Samhan and D. Fuchs-Hanusch (2016). "A framework for water loss management in developing countries under fuzzy environment: Integration of Fuzzy AHP with Fuzzy TOPSIS." Expert Systems with Applications 61: 86-105.