The Impact of Development Wetlands and Specific Tree Plantations on Hydrometeorological Adaptation and Stabilization.

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Abstract

The current research investigates at how designed wetlands, and green infrastructure can help regulate hydrometeorological variability in the semi-arid Bnaslawa sub-district of Erbil. Semi-arid regions are increasingly confronted with difficulties such as rainfall unpredictability, surface runoff, and greenhouse gas (GHG) emissions, emphasizing the need for integrated water-management solutions. GIS-based BMP siting analysis identified approximately 455.68 acres in the semi-arid Bnaslawa sub-district of Erbil as suitable locations for constructed wetlands based on hydrological, soil, topographic, and land-use parameters. The proposed willow (Salix spp.) and poplar (Populus spp.) plantation system, consisting of approximately 1.06 million trees, demonstrated significant environmental benefits with an estimated carbon sequestration potential ranging from 2,158 to 4,316 tons of CO_2 annually. SWMM hydraulic simulations showed that runoff volume and peak discharge increased with higher return periods, while constructed wetlands reduced runoff and improved stormwater management performance under extreme rainfall conditions. The vegetation also has significant biomass potential. Overall, combining wetlands with climate-adaptive planting practices is a successful, long-term strategy for reducing flood risk and increasing environmental resilience in semi-arid environments.

Keywords: Constructed wetland; Hydrometeorological; Semi-arid region; Ecological co-benefits; Stormwater management

1. Introduction

The world of hydrometeorology is evolving radically, and in the semi-arid regions, the changes are increasing. Warm temperatures, changing rain distribution, and increasing evapotranspiration are increasing the spread of drought-prone landscapes. Based on a recent study, 6.44% of the traditional humid areas of the planet are already drought-prone, a reality that demonstrates the danger of water scarcity at a global level [1]. Such changes increase the risk of soil erosion, decrease the amount of water, and jeopardize the ecology, particularly in semi-arid areas where water resources are already scarce [1].

Recent studies have shown that extreme climate events can significantly affect corporate financial performance and operational stability. An analysis of 1,517 Chinese A-share listed companies from 2013 to 2023 found that climate-related risks negatively influence business resilience and profitability. The study also demonstrated that investments in green innovation, environmental governance, and social responsibility can reduce the adverse impacts of climate disturbances. In addition, localized supply chains and improved ESG transparency were identified as important factors that enhance organizational resilience during climate-related disruptions [27].

Iraq is gradually facing problems in the hydrological system that are caused by the climate. This is evidenced by research in the Lessing Zab River Basin, a typical semi-arid catchment under normal to high emission conditions, as by the middle of the century (2041-2060) and by 2080 (2061-2080) the minimum and maximum temperatures will be increasing by +8-45% (under normal conditions), with decreases in rainfall, and an increase in evapotranspiration will also cause streamflow to reduce by as much as 31%. These estimates depict the urgency of the need to put in place the adaptation plans in a bid to cushion the Iraq water resources [2].

The Erbil in the Kurdistan region of Iraq has been made to be considered as an observatory to analyse urban and regional hydrometeorological processes in semi-arid regions. The analysis of the meteorological records of the period 1980-2021 reveals a clear warming tendency, a decline in the relative rainfall and humidity, and an increase in evaporation, which demonstrates the increased aridity of the region [3]. Based on further evidence on the urban landscape of Erbil, an increase in the land use directly impacts the surface temperatures. Even buildings, green areas, and areas with trees can be modified to make significant changes to thermal environments, and dense, diverse vegetation is the best at reducing the surface heat [4]. Groundwater assessments further prove the necessity of sustainable groundwater management because they show that the changes in the patterns of precipitation and rising temperature are leading to the decline of water tables and changing the water quality. Combined with these findings, these findings provide an insight into the mounting hydrometeorological strains in the semi-arid setting in Erbil [5].

Synthetic wetland systems have been widely adopted globally as an alternative method of decreasing water pollution caused by wastewater and enhancing the quality of water. These engineered ecosystems catch and treat agricultural and other pollutant loads in addition to their multipurpose provision of nutrient removal, biodiversity enhancement, and interaction with habitat. Although the study of artificial wetlands has been extensively researched, integrating these wetlands with specific tree species that are well-adapted to the region's semi-arid climate is a novel area of investigation. The planting of trees in artificial wetlands could also help enhance the biodiversity and structure stability, enhance shading and control of microclimate, and enhance evapotranspiration [6].

that environmental regulations may not always achieve the intended improvements in environmental performance. A study on China’s cleaner production mandate found that mandatory environmental regulations reduced carbon efficiency among regulated manufacturing firms due to increased compliance costs and reduced investment in innovation. The study further showed that the negative impacts were more pronounced in non-pollution-intensive and state-owned firms, where regulatory burdens exceeded institutional and financial capacities. These findings emphasize the importance of designing flexible environmental policies that consider firm characteristics and implementation capacity to achieve sustainable environmental outcomes [28].

It is through the combination of the artificial wetlands and the specific tree species that should have been used in the semi-arid Iraq climate that has not been given the appropriate attention she deserves, in that of the Erbil region. The current study will fill that gap by examining the innovative combination of well-selected trees in artificial wetland systems to mitigate urban runoff, suburban climate control, and the sustainability of water supply. Alongside the issue of water quality enhancement, this unified design is used to solve the problem of ecological improvement and hydrological resilience, as well as urban heat stress. Additionally, it encourages the utilization of Nature-based Solutions for ecological restoration and water security in Erbil, in line with the regional sustainable development strategies.

2. Materials and Methods

2.1 Study area

The research had been carried out in Bnaslawa, a swiftly urbanizing subdistrict southeast of Erbil, the capital of Iraq's Kurdistan Region (Latitude 36.117°N, Longitude 44.050°E) as it shown in Figure (1). throughout the last twenty years, Bnaslawa has seen significant land use change and population growth, moving from peri-urban and agricultural landscapes to a mix of commercial, institutional, and residential developments. Flooding, a drop in local water quality, and an increase in stormwater runoff have all resulted from the growth of impervious surfaces like buildings and roads [7].

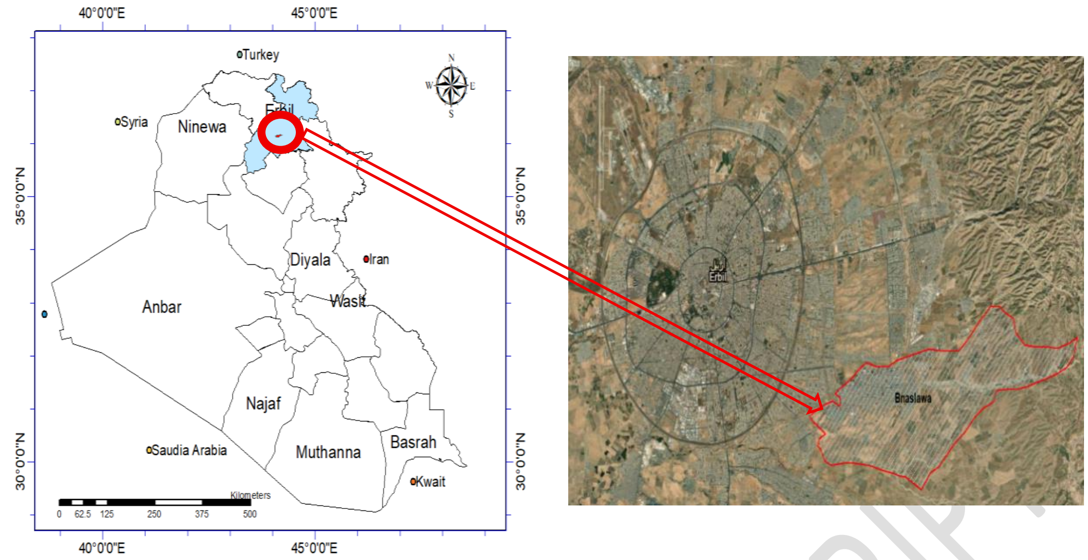

Figure 1. The study area is the actual location of Bnaslawa in Erbil, Iraq.

Bnaslawa is located in a semi-arid climate zone; it is hot and dry in summer and mild in winter. Average rainfall in the Investigation area is 250-650 mm per annum, mostly received during the months of November to March. This pattern of rainfall and poor drainage infrastructure and wastewater means that the rest of the year is dominated by protracted dry spells [8]. This dry climate has caused the region to be more vulnerable to water pollution and urban flash flooding. Bnaslawa lies between 448 and 733 meters above sea level, on a flat shallow plain. The topography and soil formation, mostly silty clay loam, found in low areas in the vicinity of open channels and undeveloped lands, provide the best conditions for implementing the surface flow or hybrid-type constructed wetlands. The subdistrict is drained by ephemeral watercourses and irrigation canals that often discharge untreated agricultural and domestic effluents into open areas or adjacent agricultural areas [9]. The spatial suitability analysis was used to select the pilot site in Bnaslawa based on the slope, land use, distance to drainage channels, and soil permeability. Since the Erbil Master Plan and the Kurdistan Regional Government Vision 2030, as discussed in this paper, have a strong emphasis on climate resilience, sustainable urban development, and water resource conservation, the site is also relevant to test the applicability of nature-based solutions in the local urban context and align them with the goals of regional planning.[10].

2.2 The Hydraulic System and Hydrology Assessment for Wetland Position

The objective is to determine how the hydrological and hydraulic conditions support wetland functionality, including storing water, accumulation time, infiltration, and discharge control, in order to identify appropriate land for wetland construction using hydraulic equations.

A detailed hydraulic and hydrologic method, specifically for stormwater wetlands or constructed wetlands, is given below:

A. Calculate the volume of runoff, The U.S. Soil Conservation Service (now NRCS) created the popular hydrological method known as the SCS Curve Number (CN) method to calculate the volume of direct runoff from rainfall events [11]. It uses empirical relationships to link rainfall, land use, soil type, and antecedent moisture conditions.

$$Q = \frac{(P-0.2S)^2}{P+0.8S}, \qquad 1$$

$$If\ P > 0.2S$$

Were

Q: Runoff (mm),

P: precipitation (mm),

S: maximum possible retention (mm),

$$S = \frac{25400}{CN} - 254\,, \qquad 2$$

CN in Bnaslawa, according to USDA TR-55 manual provides CN lookup tables. (AMC II, normal conditions). If comparable Hydrologic soil group (C) and Open space, good condition CN equal to 79.

B. Calculation of the maximum discharge, In order determining peak discharge from inadequate catchments, especially in urban and semi-urban areas, the Rational Method is a straightforward and popular technique [12]. Peak flow is expressed as,

$$Qpec = 0.278\, CIA, \qquad 3$$

Were

A: is the area that drains (m^2)

C: is the runoff measurement coefficient (Unitless).

I: is the intensity of the rainfall for a storm lasting the time of concentration(mm).

The approach helps with wetland design by ensuring that inlet and outlet structures can manage anticipated peak runoff by quickly estimating design flows based on land cover, rainfall characteristics, and watershed size.

C. To find storage volume in wetland [13], the volume of rainwater that an artificial wetland has to collect and treat in order to meet pollutant removal focusses on is referred to as the Water Quality Volume (WQv); this volume is typically around 90% of the average annual runoff.

$$Vr = 0.05 + 0.009 * I\,, \qquad 4$$

Next

$$WQv = P_{85} * Vr * A\,, \qquad 5$$

were

Vr : empirical volumetric runoff coefficient (m^3)

I: impervious fraction (Unitless)

WQv: Water quality volume (m^3) or Litre

A: Watershed area (m^2)

P 85: is the 85th percentile of the yearly precipitation depth (typically a depth of 1.5 inches in many areas).

In order for the wastewater treatment quantity to be drawn downward, usually within 24 hours, the wetland must have storage equal to WQv, taking into consideration permanent pools and extended detention zones. When combining wet and detention zones, this guarantees efficient capture of stormwater pollutant loads with a small footprint [14].

D. Hydraulic Retention Time (HRT) , is a crucial design factor that determines how long water stays in a wetland system, which has a direct impact on the effectiveness of sedimentation and pollutant removal. It is computed as the ratio of the wetland's average inflow rate (Q) to its effective storage volume (V):

$$HRT = \frac{V}{Q}, \qquad 6$$

when

HRT: Hydraulic retention time (Units of time Days, Hours, minute,)

V: Storage Volume (m^3)

Q: Discharge (m^3/day).

While too long retention periods may result in unwanted conditions including anaerobic zones, extended retention periods deliver suspended solids more time to settle and increase contact time for biological treatment processes. A typical HRT for rainfall treatment in wetland design is between two and five days, which balances hydraulic performance and treatment efficiency [15]

E. In order to ensure that the system maintains proper water levels without experiencing excessive rainfall or seasonal drying, the water balance equation is utilized in wetland design to assess the relationship between inflows and outflows. It can be defined as follows:

$$\Delta S = P + Q_{in} + GR_{in} - Et - Q_{out} - GR_{out}\,, \qquad 7$$

were

P: is rainfall (mm)

$Q_{in}$and Q_{out} : are the ground inflows and outflows (m^3/day)

GR_{in} and GR_{out} : are groundwater transfers (m^3)

ET: is evapotranspiration (mm/day)

ΔS: is the change in wetland storage (m^3).

Developers can forecast seasonal variations in water levels, maintain adequate depth for ecological processes, and stop water loss or overflow by quantifying each element. For both natural and artificial wetlands to maintain long-term hydrological sustainability, this strategy is crucial [16].

F. When determining the location's hydraulic suitability for wetland development, evaluating the ground slope is a crucial first step. In order to encourage slow water movement, enhance sedimentation, and provide sufficient contact time for the removal of pollutants, wetlands need flat or gently sloping terrain. One way to compute the slope (Sl) is to:

$$Sl = \left(\frac{\Delta H}{L}\right) * 100\ , \qquad 8$$

were

L: is the length of the flow path (m)

ΔH is the elevation change (m).

For the majority of the affected wetlands, slopes between 0.5% and 5% are ideal because higher gradients can result in erosion and rapid flow, while too flat areas can cause stagnant water and lower oxygenation. Hydraulic efficiency, stability, and successful wetland performance are guaranteed by accurate slope assessment [16].

2.3 Climate data:

The historical daily rainfall data were obtained by the Bnaslawa meteorological station, which is situated at 36.1538° latitude and 44.14° longitude. According to the Koppen-Geiger classification of climate between the years 1991 and 2000, the study site falls under the hot and summer Mediterranean climate zone (Csa). The characteristics of this type of climatic event are hot and dry summers, with an average monthly temperature of over 22°C during the hottest month, and mild and cool winters, with a majority of the precipitation received from November to March.

The precipitation is relatively seasonal, even though the average annual precipitation is between 400 and 700 mm, whereby the rainfall during the summer months is less than 10 percent of the overall. The summer period of high-pressure systems of subtropical origin causes long dry periods and high rates of evapotranspiration because subtropical high-pressure systems suppress convective activity and reduce rainfall [17, 23]. Midlatitude cyclones are also associated with winter precipitation, leading to sporadic but often heavy rainfall events. This strong climatic seasonality causes significant effects on hydrometeorological processes, such as the production of runoff, fluctuations in soil moisture, and groundwater recharge [17, 23]. The collection of data that includes 25 rainy years of 2000-2025 provides a long-term time series that is suitable for hydrometeorological investigation. Table 1 is made up of the annual record and the highest day of the year in terms of rainfall.

Table 1. Historical precipitation records for the period 2000–2025

Yearly	**Max. daily/ year (mm)**	**Yearly**	**Max. daily/ year (mm)**	**Yearly**	**Max. daily/ year (mm)**
2000-2001	98	2009-2010	45.2	2017-2018	38.9
2001-2002	25	2010-2011	48.9	2018-2019	56.7
2002-2003	60	2011-2012	16.3	2019-2020	33.5
2003-2004	38	2012-2013	35.8	2020-2021	17.4
2004-2005	33	2013-2014	44.3	2021-2022	19.5
2005-2006	63	2014-2015	29.5	2022-2023	34
2006-2007	41	2015-2016	34.1	2023-2024	40
2007-2008	27	2016-2017	32.6	2024-2025	21
2008-2009	24				

Five intervals of return have been investigated in this study: two, five, ten, Fifteen and twenty-five, years. The Weibull plotting position formula 9 has been used to identify the pertinent rainfall amount, which is:

$$R = \frac{n+1}{m} \qquad 9$$

were

R: is the return period (years),

n: is the total number of years in the record,

m: is the rank of the annual maximum rainfall value.

when the values are put in order from highest to lowest. This method uses the historical frequency of extreme events to estimate the amount of rain that falls during different return periods lacking with any parameters, as Shawn in Table 2.

Table 2. Return Period for maximum precipitation

RP (Year)	Max. P. (24) Hr.
2	34.1
5	48.9
10	60
15	63
25	98

2.4 BMP Siting tools

The BMP Siting Tool was implemented within the GIS based decision support system to find the right location of Constructed Wetlands (CWs). Some of the input data ready at the beginning of the process included a digital elevation model (DEM), land use/land cover (LULC) maps, soil texture and infiltration capacity, hydrological networks, and precipitation records. To determine the surface runoff areas that would be viewed as low-lying and which would amalgamate collected surface runoff as indicated in the figure (2), slope and flow accumulation were obtained using the DEM. Although soil data were applied to eliminate those areas with exceptionally low permeability or rocky materials that could not support the formation of wetlands, LULC data were reformulated to identify regions with impervious and agricultural lands that contribute more runoff [18].

Suitability criteria were developed using the BMP Siting Tool limits, that is, slope (<5%), proximity to drainage channels (<200 m), and minimum contributing area requirements. A raster overlay analysis was then done to combine the criteria after standardizing and weighting each one according to its hydrological importance. Constraint layers in the form of roads, protective areas, and developed areas were employed to dispose of unsuitable sites. The results of the suitability map were used to identify potential areas to locate CW, which were further narrowed down by using hydrological connectivity analysis to ensure the capture of stormwater is efficient. This is a systematic procedure that provides a scalable method to CW siting, which takes into account the urban planning, economic, and environmental considerations [14].

The relative importance of the appropriateness criteria was obtained by the Analytic Hierarchy Process (AHP). Pairwise comparisons were done using Saaty's basic 1–9 scale, where 1 represents equal relevance and 9 represents excessive importance of one criterion over another , as it shown in Table 3. The evaluations were based on the relative impact of each criterion on the performance of the created wetlands and the efficacy of the stormwater management. The consistency of the pairwise comparison matrix was checked using Consistency Ratio (CR) and values less than 0.10 were accepted [29].

Table 3. AHP Pairwise comparison matrix

Criteria	Slope	LULC	Impervious Ratio	Soil Type	Distance to Drainage	Contributing Area
Slope	1	3	2	4	1/3	1/4
LULC	1/3	1	1/2	2	1/5	1/6
Impervious Ratio	1/2	2	1	3	1/4	1/5
Soil Type	1/4	1/2	1/3	1	1/6	1/7
Distance to Drainage	3	5	4	6	1	1/2
Contributing Area	4	6	5	7	2	1

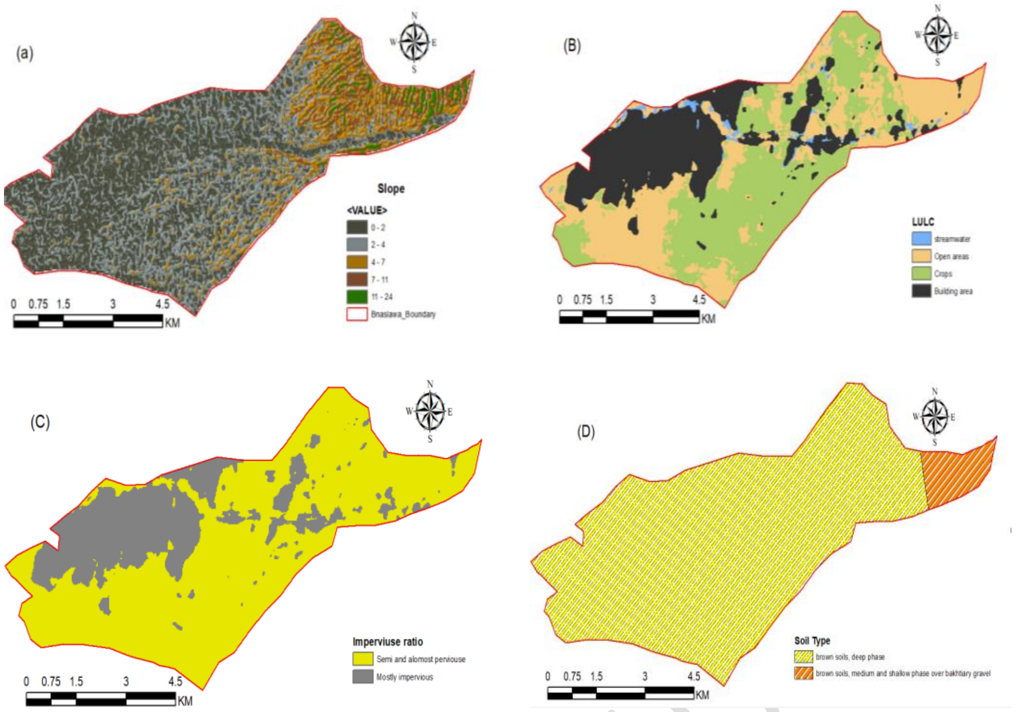

Figure 2 represents the spatial distribution of the main parameters applied to the suitability evaluation for hydrological and green infrastructure: (a) slope ratio; (b) land use/land cover; (c) imperviousness ratio; and (d) soil type.

2.5 Classification of wetlands

The two basic categories into which constructed wetlands (CWs) can be broadly classified are surface flow systems and subsurface flow systems. A simple and popular classification divides subsurface flow (SF) treatment wetlands and free water surface (FWS) wetlands when in reality there are numerous other systems of classification that have been proposed in the extant literature. Subsurface flow wetlands are also divided into vertical flow (VF) and horizontal flow (HF) wetlands depending on the direction of the water movement [15].

In FWS wetlands (also referred to as surface flow wetlands), water passes through thick vegetation and over the media bed. Subsurface flow wetlands, conversely, retain water under the surface of a porous substance, such as soil, rock, sand, biochar, or other filter material. Post-treatment is often carried out in SF wetlands, particularly HF and VF. Also, the VF wetlands are introduced and have been effectively applied in the treatment of the screened raw wastewater. Conversely, FWS wetlands are normally used in the tertiary level of treatment [16].

The combination of different CW systems has been developed to provide greater treatment efficiency through the construction of flexible wetland systems. Such systems are usually configured with two or more stages and they are often configured in parallel. Other innovations that have been introduced to improve the performance of CWs in the recent past include aerated CWs, baffled flow CWs, step-feeding CWs, and circular flow corridor CWs. In Figure 3, a schema illustration has been used to depict the various types of artificial wetlands [16].

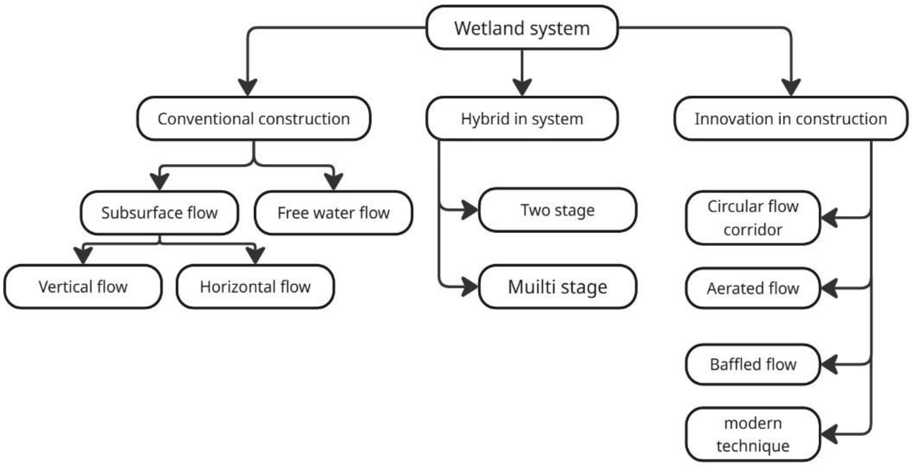

Figure 3: Diagram illustrating the hypothetical wetland classification system utilized in this research.

2.6 Relation between GHG, wetland and hydrometeorological changes:

One of the biggest causes of the existing climate change is a buildup in the amount of greenhouse gases (GHGs) and, in particular, carbon dioxide (CO_2) that has a critical impact on hydrometeorological systems. The greenhouse effect induced by high CO_2 concentration increases the atmospheric temperature, and this disrupts the hydrological cycle. Warming increases and destabilizes the water cycle since it leads to a higher rate of evapotranspiration, higher atmospheric capacity to hold moisture, and high evaporation rates [17]. This hydrological acceleration is manifested by increased and more severe frequency and intensity of major weather conditions such as floods and droughts, more erratic precipitation, and altered soil moisture and runoff regimes [18]. These changes decrease the predictability, reliability, and stability of the distribution of water resources, a phenomenon that can be cognized as a sort of hydrometeorological degradation of the system behaviours. Indicatively, in catchments conceptualized under conditions of climate change, large decreases of river discharge and water yield, up to about 60 percent in certain areas, have been estimated, which are caused by increases in temperature and decreases in precipitation [19]. Equally, surface areas and water levels of reservoirs and lake surfaces experience considerable declines in surface area and water levels during warming conditions, particularly in semi-arid or endorheic areas. The diminished stability and reliability of the hydrological systems due to the climate change caused by GHG is therefore called hydrometeorological reduction. The GHG emissions in this case result in increased CO_2 that consequently leads to atmospheric warming, an increased hydrological cycle, and reduced hydrometeorological stability. Improving adaptive management of water resources and ensuring water security, particularly in regions already facing a water shortage or water extremes, require knowledge and measurement of these interactions [20].

2.7 Plants for wetland

The plants that can be used to reduce greenhouse gas (GHG) emissions in wetland ecosystems are of various types, with some of them being especially efficient in carbon sequestration. An example of such a plant would be the very successful willow (Salix spp.) due to its quick growth and massive ability to store carbon, which is estimated to be 5-10 t CO_2/ha/year. Besides minimization of greenhouse gas emissions, willow is one of the best plants that can be used in the wetlands because it can withstand the saturated soil and also manage erosion [21, 24]. In the same spirit, poplar (Populus spp.) is an acceptable choice due to the rapid growth rate and higher carbon sequestration capacity (6 to 12 t CO2/ha/yr.) it can withstand in addition to their high adaptability to wetlands, poplars are also useful in the production of biomass energy and short-rotation forests [23]. When joined together, these species play a major role in enhancing the addition of carbon and the resilience of wetland ecosystems.

2.8 Validation of results

Validation of the SWMM model was performed by comparing the simulated runoff response with the observed one using three common statistical indicators: coefficient of determination (R2), Nash–Sutcliffe Efficiency (NSE) and Percent Bias (PBIAS) as it present in Table 4. These metrics were chosen to test the model's capacity to replicate the magnitude, variability and general trends of the observed hydrological data.

The coefficient of determination (R2) was used to assess the strength of the linear association between observed and simulated values, with R2 more than 0.80 deemed very strong, R2 between 0.70 and 0.80 considered good, and R2 above 0.60 considered acceptable. The Nash–Sutcliffe Efficiency (NSE) was used to assess the prediction accuracy of the model, where values more than 0.75 are considered very excellent, values between 0.65 and 0.75 are considered good, and values between 0.50 and 0.65 are considered acceptable. The Percent Bias (PBIAS) was used to assess the average propensity of the simulated values to over- or underestimate the observed. Model performance was assessed as very excellent for PBIAS within ±10%, good within ±15%, and acceptable within ±25% [30].

Table 4 Statistical analyses criteria for validity of results

PBIAS	R^2	NSE	Performance
±10%	>0.80	>0.75	Very Good
±15%	>0.70	0.65–0.75	Good
±25%	>0.60	0.50–0.65	Acceptable
		<0.50	Unsatisfactory

3. Result and Discussion:

3.1 Analytic Hierarchy Process (AHP)

The relative importance of each aspect for appropriateness of created wetlands and efficacy of stormwater management was evaluated using pairwise comparison and the Analytic Hierarchy Process (AHP) to get the criterion weights. Contributing drainage area and closeness to drainage channels were given more priority since they impact runoff collection and hydraulic connection as present in Table 5.

Table 5 Derived criterion weights obtained from the Analytic Hierarchy Process (AHP) for constructed wetland suitability assessment.

Criterion	Weight (%)
Contributing Area	34
Distance to Drainage	26.7
Slope	16.3
Impervious Ratio	10.5
LULC	7.4
Soil Type	5.1

Consistency of the matrix of pair wise comparisons was verified using Consistency Ratio (CR) as it shown in Table 5. The result of the consistency ratio was 0.066 which is less than the allowable value of 0.10. The obtained criteria weights were used in the weighted overlay analysis to develop the final suitability map for the location of built wetlands.

Table 6. Consistency assessment of the AHP pairwise comparison matrix, including the maximum eigenvalue (λmax), Consistency Index (CI), Random Index (RI), and Consistency Ratio (CR).

Parameter	Value
Number of Criteria (n)	6
λmax	6.41
Consistency Index (CI)	0.082
Random Index (RI)	1.24
Consistency Ratio (CR)	0.066

3.2 Identifying the location

Hydrologic Soil Group C (brown soil, deep phase) was found in the southwest, whereas Group D soils (brown soil, deep, medium, and shallow phases over Bakhtiari gravel) were found in the northeastern sector. Groundwater depths varied from 150 to 450 m. A 30 m stream buffer was used to protect biological integrity and confine development to publicly accessible land.

The suitability analysis revealed that the southeast section of the study area was the most suitable site for built wetland development, comprising about 455.68 acres (Figure 4). It was ranked as the most suitable place since it fulfilled many hydrological and environmental conditions simultaneously. The site is characterized by moderate slopes that Favor water retention and limit building limitations, while its closeness to the drainage network Favors hydraulic connection and Favors effective runoff collecting. The availability of undeveloped land permits wetland creation and reduces potential problems with existing infrastructure. Furthermore, the soil characteristics are conducive to moderate infiltration capacity and enough runoff production to support both water storage and treatment activities. The site also gets runoff from upstream built and impermeable regions, which may increase its potential efficacy for stormwater management. Additionally, the site meets ecological buffer criteria and is located in a hydrologically linked region capable of capturing and holding runoff prior to downstream disposal. Together these reasons explain the better performance of the southeastern sector compared with other regions of the watershed.

The findings show that the relationship between topography, soil properties, hydrological connectivity, land use patterns and environmental restrictions greatly affects the appropriateness of created wetlands. The use of GIS based spatial analysis with the BMP Siting Tool offers a systematic and evidence-based approach for the identification of sustainable sites for the deployment of green infrastructure.

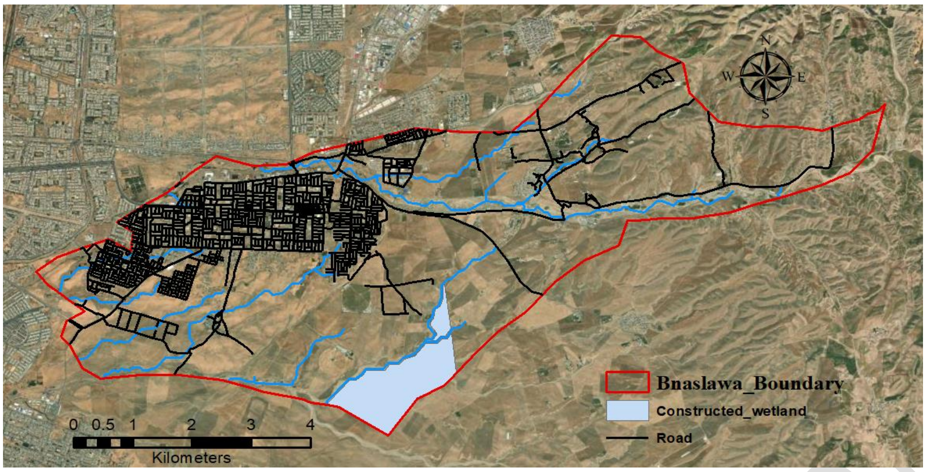

Figure 4 ; shows the geographic distribution of land suitability for constructed wetlands within the investigation area based on GIS-based BMP Siting outcome data.

3.2 GHG Prevention and Tree Planting Demands

The suitability evaluation suggested that a mixed plantation of willow (Salix spp.) and poplar (Populus spp.) would be suitable for improving carbon sequestration at the same time supporting wetland restoration within the proposed site. Based on the available planting space of 455.68 acres, around 922,213 trees were projected utilizing spacing arrangements of 2 × 2 m for willow and 3 × 3 m for poplar. The planting pattern designated 80% of the land (364.54 acres) to willow and 20% (91.14 acres) to poplar. A 15% over-planting allowance was included to compensate for establishment losses and early-stage mortality, resulting in a total demand of roughly 1.06 million trees, comprising 954,500 willow and 106,045 poplar individuals.

Both willow and poplar species have been well known for their fast growth and capability of carbon sequestration. The reported sequestration rates are 5-10 t CO 2 ha -1 yr -1 for willow [24] and 6-12 t CO 2 ha -1 yr -1 for poplar [25]. Extrapolating these rates to the projected plantation area the potential carbon removal is of around 2,158-4,316 t CO2 per year. In addition to carbon storage, these plants may also provide soil stability, erosion control, habitat restoration and wetland ecological function improvements.

However, large-scale plantation growth in semi-arid areas needs careful ecological attention. Willow and poplar species often have a rather high demand for water, and if planting density is not carefully controlled, this might affect local water balances. Hence, it is important to promote the selection of varieties appropriate to local requirements and compatible with the current hydrological conditions. And, plantation design should retain habitat variability and prevent replacing natural vegetation groups that sustain local biodiversity. Where possible, tree plantings may be able integrated with manmade wetland systems and remnant natural vegetation to improve ecosystem resilience while minimizing potential effects on water supplies and ecological integrity. Appropriate strategies for management of willow as well as poplar plantings may provide climate mitigation and ecosystem restoration advantages in semi-arid areas.

3.3 Hydraulic Evaluation of Storms in the Recurring Time Period

The results of hydraulic simulations using SWMM for computations of the highest 24-hour precipitation under five different return periods are shown in Table 7. There is a clear trend in the study in which maximum runoff and total runoff continue to increase with increasing intensification of precipitation. Extreme rainfall events, which are linked to high return periods, make the runoff much greater and faster than when the period is low and thus produce a moderately large amount. It aligns with the theoretical forecast that more intense storms will exceed the ability of the soil to absorb the precipitation at a faster rate, resulting in greater percentages of direct surface runoff.

Increase in peak runoff due to hydraulic perspective has a direct influence on the development of downstream water management infrastructure, specially constructed wetlands. An increase in peak flows enhances the likelihood of hydraulic overloading that can compromise the structural integrity of the wetland system in addition to interfering with its treatment efficacy. These results show that to successfully reduce the height of floods and the time of residence needed in enhancing the quality of water in extreme storm conditions, a larger storage space is needed. To be more precise, it has been calculated that, given long periods of returns, the storage capacity should be expanded correspondingly to the expected increase in the runoff amounts. This observation signifies the importance of comprehensive hydrological study in the pre-sizing of wetlands as the best management practices (BMPs).

They also emphasize the significance of incorporating the precipitation based on the return period in wetland design. Hydraulic loading can be underestimated as a result of traditional design approaches based on average or short-period rainfall measurements and the probability of the system failure during a high event. Consideration of the highest amount of precipitation per day in varying periods can enhance the strength and flexibility of a conceptual framework. This also assures that, although the climatic and hydrometeorological conditions change, the wetlands would still be able to fulfil their long-term ecological and hydrological functions besides the reduction of peak discharges

Table 7 The results of hydraulic simulations using SWMM based on return periods and various precipitation situations. The table illustrates the growing hydraulic load connected to occurrences with longer return periods by showing changes in runoff volume, peak discharge, and system response.

Return period R.P. (Year)	P. (24) Hr.	Runoff (mm)	Peak Flow (m^3/s)	Runoff (mm) after CW	Peak Flow after CW(m^3/s)	Storage Volume (10^3) m^3
2	34.1	7.03	53.3	4.5 (-35%)	39.4 (-25%)	53.3
5	48.9	11.39	89.42	7.74 (-32%)	62.5 (-30%)	89.42
10	60	14.84	118.11	10.4 (-30%)	83.8 (-29%)	118.11
15	63	15.87	127.5	10.33(35%)	89.2 (-30%)	127.5
25	98	27.99	230.879	16.8 (-40%)	166 (-28%)	230.879

3.4 Validation of result

However, due to the lack of hydrological data in the research region, the SWMM model could not be directly calibrated and validated. Thus, model parameters were allocated based on published values from watersheds with comparable climate, soil, and land-use characteristics. The dependability of the model was tested using sensitivity analysis, comparison with the SCS-CN approach, and evaluation against performance ranges from earlier research.

The sensitivity study consisted of adjusting important hydrological factors such as Curve Number (CN), impervious surface ratio, Manning's roughness coefficient, depression storage, and hydraulic conductivity to identify their effect on runoff volume and peak discharge. The findings showed that Curve Number and imperviousness were the most sensitive characteristics influencing model outputs whereas Manning's roughness coefficient and depression storage were somewhat sensitive.

To evaluate the performance of the model, conventional assessment metrics for hydrological models like Nash–Sutcliffe Efficiency (NSE), the coefficient of determination (R2), Percent Bias (PBIAS) and Root Mean Square Error (RMSE) were used. $NSE > 0.50$, $R^2 > 0.60$, PBIAS ± 25% and RMSE reduced were regarded satisfactory performances.

The simulated efficacy of the planned built wetland was further evaluated by comparison with the values provided in the literature. The estimated runoff volume reductions by SWMM were 32% to 40%, which are equivalent to the range of 25% to 50% reported for created wetlands with similar hydrological [22,26] circumstances. The good agreement of simulated results with reported performance ranges supports the trustworthiness of model predictions and usefulness of the proposed wetland system for stormwater management and runoff reduction.

4. Conclusion:

This research, which focused on the Bnaslawa sub-district of Erbil, showed that there is also an organized method of developing and evaluating artificial wetlands within a semi-arid setting, the preliminary phase was identifying the suitable location, and this was done through the ecological, geological, and soil properties to ensure that the location where wetlands are installed fulfils the requirements of the drainage, slope, and soil group to achieve a well-functioning wetland. The GIS based suitability evaluation was successfully used to identify the optimum areas for installation of the created wetlands within the research area. High potential locations for stormwater management were delineated by an integration of slope, land use/land cover, impervious surface ratio, soil properties, proximity to drainage channels, and contributing drainage area using an AHP-weighted overlay analysis. The chosen location has suitable topography, hydrology and land use characteristics, conducive to the efficient collection, conveyance and storage of run-off. The AHP's consistency weighing procedure assured the dependability of the suitability evaluation, while the inclusion of exclusion factors increased the practicality of site selection. and then that, the hydraulic simulations made some understanding of the runoff dynamics possible under different return periods, which showed that the layout was also improved by the selection of vegetation to enhance the ecological efficiency of the layout. Willow (Salix spp.) and poplar (Populus spp.) were selected as appropriate types because they can withstand semi-arid conditions and have been illustrated to be efficient in wetland systems in enhancing the quality of water, biomass productivity, and carbon uptake. The plantation method is sustainable, as it makes the ecosystem stable over time and more resistant to seasonal differences by mixing both species.

In addition, the results focus on how wetlands mitigate greenhouse gas emission besides acting as hydrological controls. Through sequestration of carbon and the possibility of reducing the methane emissions when compared to the conventional unmanaged wetlands, they offer two benefits: they safeguard communities due to hydrometeorological variability, and they have a direct role in global warming adaptation and mitigation.

Everything said and done, it suggests that well-designed artificial wetlands can be used as a versatile natural solution to semi-arid regions. It offers a viable template of sustainable management of water and land in Iraq and in other similar settings across the globe by synergizing site selection criteria, hydraulic performance, ecological potential, and climate co-benefits.

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Abbreviations

The following abbreviations are used in this manuscript:

GHG	Green House Gas
SWMM	Storm Water Management Model
BMP	Best management practice

References:

[1] Li, Qiaoqiao, Aizhong Ye, Yoshihide Wada, Yuhang Zhang, and Junju Zhou. "Climate change leads to an expansion of global drought-sensitive area." *Journal of Hydrology* 632 (2024): 130874.

[2] Saeed, Fouad H., Mahmoud S. Al-Khafaji, and Furat A. Al-Faraj. "Spatiotemporal hydroclimatic characteristics of arid and semi-arid river basin under climate change: a case study of Iraq." *Arabian Journal of Geosciences* 15, no. 14 (2022): 1260.

[3] Hamed, Masoud Hussein. "Climate Parameter Uses as Indices For Assessment of Climate Change and Water Balance in Erbil Sub-Basin North–Iraq." *Iraqi Journal of Science* (2023): 4518-4537..

[4] Ismail, Suzan, and Hamid Maliki. "Spatiotemporal landscape pattern changes and their effects on land surface temperature in greenbelt with semi-arid climate: A case study of the Erbil City, Iraq." *Journal of Arid Land* 16, no. 9 (2024): 1214-1231.

[5] Mustafa, Jwan Sabah, and Dana Khider Mawlood. "Estimating of groundwater recharge in North, Central, and South Basin of Erbil." *Mathematical Modelling in Civil Engineering* 18, no. 1 (2023): 14-24.

[6] Préau, Clémentine, Julien Tournebize, Maxime Lenormand, Samuel Alleaume, Véronique Gouy Boussada, and Sandra Luque. "Habitat connectivity in agricultural landscapes improving multi-functionality of constructed wetlands as nature-based solutions." *Ecological Engineering* 182 (2022): 106725.

[7] Saleem, B.K.M. and Suleimany, J.M.S., 2026. Mitigating hydro-meteorological risks with nature-based-solutions in semi-arid region. *Kuwait Journal of Science*, p.100604.

[8] Taha, Senik Tahir Mahmood1-Hakim Qadir, and Mahmood Muhammad Hamza. "Causes of School Dropouts in the Kurdistan Region of Iraq in 2021." (2025)..

[9] Jirjees, Shevan Jameel. "Climatic Parameters Use for Evaluating Water Budget and Drought Analysis in Erbil Sub-basin, Kurdistan Region, Northern-Iraq." *Zanco Journal of Pure and Applied Sciences* 36, no. 5 (2024): 47-55..

[10] Shekha, Yahya Ahmed. "The effect of Erbil city wastewater discharge on water quality of Greater Zab river, and the risks of irrigation." *PhD, university of Baghdad* (2008).

[11] Osman, Magued. "Kurdistan region of Iraq population analysis report." *Kurdistan Region Statistics Office in Kurdistan Regional Government* (2021).

[12] Cronshey, Roger. *Urban hydrology for small watersheds*. No. 55. US Department of Agriculture, Soil Conservation Service, Engineering Division, 1986.

[13] Maidment, David R. "GIS and hydrologic modeling-an assessment of progress." In *Third International Conference on GIS and Environmental Modeling, Santa Fe, New Mexico*. 1996.

[14] Tao, Wendong, Keshav Sauba, Kazi P. Fattah, and John R. Smith. "Designing constructed wetlands for reclamation of pretreated wastewater and stormwater." *Reviews in Environmental Science and Bio/Technology* 16, no. 1 (2017): 37-57.

[15] Lee, Joong Gwang, Ariamalar Selvakumar, Khalid Alvi, John Riverson, Jenny X. Zhen, Leslie Shoemaker, and Fu-hsiung Lai. "A watershed-scale design optimization model for stormwater best management practices." *Environmental Modelling & Software* 37 (2012): 6-18.

[16] Fletcher, Tim D., William Shuster, William F. Hunt, Richard Ashley, David Butler, Scott Arthur, Sam Trowsdale et al. "SUDS, LID, BMPs, WSUD and more–The evolution and application of terminology surrounding urban drainage." *Urban water journal* 12, no. 7 (2015): 525-542.

[17] Masoud, Ahmed MN, Amani Alfarra, and Sabrina Sorlini. "Constructed wetlands as a solution for sustainable sanitation: A comprehensive review on integrating climate change resilience and circular economy." *Water* 14, no. 20 (2022): 3232.

[18] Istenič, Darja, Igor Bodík, Maret Merisaar, Magdalena Gajewska, Michal Šereš, and Tjaša Griessler Bulc. "Challenges and perspectives of nature-based wastewater treatment and reuse in rural areas of central and eastern Europe." *Sustainability* 15, no. 10 (2023): 8145.

[19] Douville, Hervé, Krishnan Raghavan, James Renwick, Richard P. Allan, Paola A. Arias, Mathew Barlow, Ruth Cerezo-Mota et al. "Water cycle changes." (2021): 1055-1210.

[20] Wang, Xander, and Lirong Liu. "The impacts of climate change on the hydrological cycle and water resource management." *Water* 15, no. 13 (2023): 2342.

[21] Colín-García, Gerardo, Enrique Palacios-Vélez, Adolfo López-Pérez, Martín Alejandro Bolaños-González, Héctor Flores-Magdaleno, Roberto Ascencio-Hernández, and Enrique Inoscencio Canales-Islas. "Evaluation of the impact of climate change on the water balance of the Mixteco River Basin with the SWAT model." *Hydrology* 11, no. 4 (2024): 45.

[22] Dentinho, T., G. Saspugayeva, and A. Zhaken. "Sustainable development of the Esil River Basin: an intersectoral approach and scenario analysis." *BULLETIN of the LN Gumilyov Eurasian National University. Chemistry. Geography. Ecology Series* 151, no. 2 (2025): 237-254.

[23] Peel, Murray C., Brian L. Finlayson, and Thomas A. McMahon. "Updated world map of the Köppen-Geiger climate classification." *Hydrology and earth system sciences* 11, no. 5 (2007): 1633-1644.

[24] Kuzovkina, Yulia A., and Timothy A. Volk. "The characterization of willow (Salix L.) varieties for use in ecological engineering applications: co-ordination of structure, function and autecology." *Ecological Engineering* 35, no. 8 (2009): 1178-1189.

[25] Stanturf, John A., Cees Van Oosten, Daniel A. Netzer, Mark D. Coleman, and C. Jeffrey Portwood. "Ecology and silviculture of poplar plantations." *Poplar Culture in North America* Part A (2001): 153-206.

[26] Kadlec, R. H. "Comparison of free water and horizontal subsurface treatment wetlands." *Ecological engineering* 35, no. 2 (2009): 159-174.

[27] Lei, X., 2026. When Hurricanes Rewrite Balance Sheets: The Climate Adaptation Paradox in Corporate Resilience. *Sustainable Development*, *34*(1), pp.1007-1019.

[28] Lei, X. and Kocoglu, M., 2025. When good intentions meet bad outcomes: Evidence from China's cleaner production mandate. *Energy Economics*, p.109030.

[29] Saaty, T.L., 1990. The analytic hierarchy process: planing, priority setting, resource allocation.

[30] Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, *50*(3), pp.885-900.