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Impact of Climate Variability on Reservoir Based Hydro-power Generation in Jebba Dam, Niger State, Nigeria

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ABSTRACT

This study examined impact of climate variability on reservoir-based hydro-power-generation in Jebba dam, Niger State of Nigeria. Data of rainfall, temperature, evaporation, reservoir inflow and outflow and power output for thirty-one years were obtained from Jebba Hydropower Station [JHP]. The Man-Kendall and Pearson’s Product Moment Correlation Coefficient (PPMCC) were used to establish the influence of weather parameters on the reservoir inflow and outflow. Findings showed increased electricity generation during dry season than wet season. The highest annual mean amount of the electricity generated was in 2016 having mean of 689.12 mwh, dry season (352.26 mwh) and wet season (336.86 mwh). Reservoir inflow showed a negative trend with severe fluctuations in 1998 (1436.42 M3/Sec), 1999 (1581.08 M3/Sec) and 2010 (1641.08 M3/Sec) with a steady increase in 2016 (1556.00 M3/Sec), 2017 (1556.42 M3/Sec) and 2018 (1635.75 M3/Sec). The reservoir outflow pattern showed tremendous and negative trend in fluctuation with increase in 1998 (1421.75 M3/Sec) 1999 (1581.58 M3/Sec) and 2010 (1641.16 M3/Sec) and a steady increase in 2016 (1535.00 M3/Sec), 2017 1558.83 M3/Sec and 2018 (1632.00 M3/Sec). Thus, rainfall and reservoir inflow had strong relationships with the amount of power generated than temperature and evaporation. Therefore, the government should increase the water carrying capacity of the reservoir construction by storing water to be used during dry periods.

1. Introduction

Climate is the average atmospheric condition of a particular place at a particular time over a long period of time ranging from 30-35 years [1]. Also, [2] reveals that climatic conditions of a geographic location will determine the availability of water resources from 30-35 years. Rainfall, evaporation and temperature have more influence and affect hydroelectricity performance since they are interrelated with other elements of weather [3]. It is predicted that in the world, energy consumption will double between the years 2007 and 2035 [4]. Researchers have projected that the population of the world will be above 10 billion persons around 2050 and will rise above 11.2 billion in the year 2100 [5]. Thus, it is very clear that the present population of people is severely demanding energy service and water resources resulting from the rise in population. However, the next four decades will witness pressure in energy and water resources as various dams will influence power demand and control water supply in some regions.

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However, evaporation, temperature, rainfall pattern alters global hydropower production. The changes in these patterns are mostly caused by climate change. The rise in demand for electricity will continuously put pressure on electric power decision for countries, especially with the increased pollution by the greenhouse gas \[8\].

According to \[7\] temperature and reservoir inflow are also important in the generation of electricity; due to the fact that rise in temperature will result in higher evaporation from water bodies thereby reducing the quantity of available water. When the rate of evaporation is greater than the rate of precipitation, it will result in water scarcity. Thus, this process needed to be investigated in a drainage basin where hydroelectric power dam is usually hosted by the reservoir as there is suspected loss of water through evaporation and their effects in loss of water. The phenomena of evaporation and water loss are very crucial in understanding the amount of reservoir discharge and energy supply in the study of dams. These have yielded to the interest in the study of climatic systems and biophysical modifications of drainage basins in order to cope with the problems of electric power generation and management.

However, hydropower stations are facing tremendous challenges as a result of climatic change; communities, companies and businesses are affected because of the fluctuation of electric power. This has effects on small-and large-scale businesses, and, consequently the Gross Domestic Product (GDP) of Nigeria. However, \[3\] studied weather elements, inflow of reservoir and their patterns in Kainji dam of Niger State, Nigeria, where rainfall, temperature, evaporation and inflow parameters were considered, neglecting the effect of outflow on energy discharged. But in the case of this research, rainfall, temperature, evaporation, inflow and outflow were considered, though they have an element of similarity but in different locations.

Energy is one of the commodities in which the provision of goods and services depends. Its availability and consumption rate are economic index for measuring the development of any community \[8\]. In Nigeria, there is a limitation to power supply from the national grid which has adversely affected the economic and social development of the populace. This really necessitates the need for decentralized power source as a viable alternative to which hydro power schemes readily fit in. Major rivers and dam development provide an enviable energy potential for the exploitation of hydro energy in Nigeria. The problem of electricity generation in the country is on the increase on a daily basis as both urban and rural dwellers need electricity. Jebba dam is one of the major producers of electricity in Nigeria though not enough to meet the demand of the growing population; this is why the need for the assessment of the water resources in some areas becomes so important in order to meet internal and external demands. Ever increasing demand for electricity has intensified the quest for generation per kw and for an increase in production. The dam, river discharge and turbines alone will not improve productivity if significant deterioration of natural condition occurs. It is in the light of this that this study is justified.

\[9\] revealed that Africa and other developing countries will incessantly have severe effects of climate change and water resources. \[10\] showed that Africa, especially Nigeria and other sub-Saharan countries will be knocked by climate change phenomenon due to their high values of climatic parameters. Generally, the effects of greenhouse gases will affect solar intensity, rainfall, temperature, humidity, pressure and other variables of climate, thereby influencing reservoir discharge and electric power supply in Jebba Reservoir \[5\]. This study explores the effects of various climatic variables of rainfall, temperature, evaporation and the inflow-outflow reservoir data to understand their relationships in order to manage Jebba dam hydro-electric power project in Nigeria. Therefore, this research focuses on the impact of climate variability on reservoir-based hydro-power-generation of Jebba dam, Niger State, Nigeria.

2. Methodology

The Jebba Hydroelectric Power Station is situated at the terrain of River Niger in Nigeria which is founded within latitudes 9°10’N to 9°55’N and longitudes 4°30’E to 5°00’E (Figures 1 and 2). The area has an altitude of 76 meters Above Sea Level (ASL) which is approximately 100 kilometers downstream of Kainji dam \[6\]. The Jebba dam is an earth dam and the third functional hydro-power project in Nigeria with capacity to generate 578 MW power, having six (6) turbines of 96.4 MW each, distributed to over 364,000 households with operating-head of 27.6 m. Thus, the turbines are joined to a generator having 119 MVA maximum continuous rating and 103.50 MVA base load rating respectively \[10\].

Data for reservoir inflow, reservoir outflow and amount of power generated as well as climatic variables of rainfall, evaporation and temperature for the period of thirty years (1988-2018) were obtained from Mainstream Energy Solution Limited, Hydro-Power Plant, Jebba. The annual mean variable was computed using simple statistics. The amount of power generated during the rainy and dry seasons within the last thirty-one years was analyzed by getting the grand total seasonal mean of power generation within the study period. Man-Kendall analysis was...
adopted to understand the monotonic trend of rainfall, evaporation, temperature and reservoir flow patterns and displayed on the graph. The interactions of rainfall, evaporation and temperature patterns on the reservoir inflow and outflow were determined using the Pearson Moment Correlation Co-efficient in the environment of the Statistical Package for Social Scientist (SPSS).

Figure 1. Niger State in Nigeria

Figure 2. Jebba in Mokwa LGA of Niger State

3. Results

The result in Figure 3 showed the trend in rainfall in the study area which fluctuated over the years and the pattern showed gradual steady increase between 1988-1991 (79.99 mm, 93.92 mm, 94.24 mm and 121.90 mm respectively) and decreases between 1992-1994 (86.54 mm, 82.93 mm and 81.37 mm respectively). However, amount of rainfall received in Jebba reservoir dropped drastically in 2009 (77.81 mm). The amount of rainfall received in Jebba reservoir was fluctuated throughout the study period. Thus, Figure 4 showed that the temperature of the study area was on a steady increase between 1991 and 2005 with little fluctuations in some years and decreased sharply in 2016 (33.00°C) with a sharp increase in 2010 having 36.00°C which could result from climate change.

It was shown in Figure 5 that the evaporation in the study area for the time frame moderately fluctuated and gradually increased and dropped significantly to an average of 16.16 M^3/Sec in 2011. Also, the average evaporation for 2004 was 10 mm while the amount of power generated in 2004 was one of the highest with 328.33 MWH recorded. High rate of evaporation was capable of reducing the amount of water in the reservoir, thereby resulting to shortage in power generation. Figure 6 displayed the inflow pattern in negative trends having different degrees of fluctuations between 1990 and 2015, rise in 1998, 1999 and 2010 (1436.42 M^3/Sec, 1581.08 M^3/Sec and 1641.08 M^3/Sec respectively) and a steady increase in 2016, 2017 and 2018 (1556.0042 M^3/Sec, 1556.4242 M^3/Sec, and 1635.7542 M^3/Sec respectively).

The Figure 7 indicated the outflow pattern showing negative trends in varying degrees of fluctuation between 1990 and 2015, rise in 1998, 1999 and 2010 at the rate of 1421.75 M^3/Sec, 1581.58 M^3/Sec and 1641.16 M^3/Sec, had stable increase in 2016, 2017 and 2018 at the rate of 1535.00 M^3/Sec, 1558.83 M^3/Sec, and 1632.00 M^3/Sec respectively.
There were trends and fluctuations in the amount of power generation in the study area. Figure 8 showed the trend and variations in the amount of power generated in both dry and wet seasons. The lowest amount of electricity was generated in wet and dry seasons in 1993 (182.00 mwh and 158.24 mwh) while the highest amount of electricity was generated during the wet season in 2016 (352.26 mwh) and 1999 (352.26 mwh) in the dry season. But the highest annual mean amount of the electricity generated was in 2016 with the average mean of 689.12 mwh for both dry and wet seasons (352.26 mwh and 336.86 mwh).

The correlations between various climatic variables, reservoir inflow, reservoir outflow and power generation were carried out at 0.05 level of significant. Table 1 indicated that the correlation between rainfall amount and power generation was 0.370. This showed a moderate positive correlation significance between rainfall and power generation which revealed that an increase in rainfall could result in an increase in the amount of power generated and vice versa. The Table 1 still showed the value of 0.178 correlation between temperature and the quantity of power discharged. This showed a weak positive significant relationship between temperature and quantity of power discharged. This revealed that temperature does not really affect power generation in the study area.

Furthermore, as still the Table 1 showed the correlation between evaporation and power generated was -0.268. This showed a weak negative correlation between evaporation and the amount of power generated. This revealed that evaporation had little or no impact on the amount of power generation in the reservoir. The table displayed reservoir inflow and quantity of discharged power were correlated at 0.875. This showed a strong significant positive relationship. It revealed that a change in reservoir inflow will surely affect the amount of power generated. The Table 1 showed that reservoir outflow and power generated had correlation of 0.878. This also showed strong significant positive relationship, indicating that change in reservoir outflow would significantly affect the amount of power generated.

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*Significant at 0.05 level

4. Discussion

The study has demonstrated that the trend of each variable (climatic and reservoir variables) for the period under study is subjected to fluctuation, which could be as a result of climate change over the years. Similarly, [11] studied the impacts of climate change on the water resources of Jebba hydropower reservoir. The study shows some no-
table changes in the climate of Jebba hydropower station. It reveals that in the past few years, rainfall and relative humidity have exhibited negative trends in the area. This indicates that climatic parameters have the tendency to influence reservoir characteristics. In the study the evaporation loss shows negative trends resulting from low relative humidity. According to the result, there exist a positive impact of climate variables on reservoir water discharge.

Thus, statistical analysis for the amount of power generation reveals that there is increased electricity generation during dry season than the wet season, though the two seasons exhibit fluctuations at different levels. This could be as a result of the high surface flows toward dry season period. This is in tandem with the findings of [3] and other scholars who show that months/period with higher inflow is expected to have a high amount of power generation. The study shows that since more inflow is being received towards months of dry season it is expected that more electricity will be generated in this period. Nevertheless, the amount of power generated in September and October is high and can be compared to the amount generated in the dry season months. While the month of July marks the period with the lowest amount of power generation with the lowest average mean in the study area.

Moreover, the result of the Pearson Correlation Co-efficient revealed that rainfall, reservoir inflow and outflow have a significant relationship with the amount of power-generated than other parameters. This means that, a drop in the amount of rainfall or inflow will definitely affect the amount of power-generation, which will consequently affect the outflow. In the same vein, [12] studied various parameters that influence reservoir discharge in Jebba hydropower. These elements include peak inflow, storage balance, evaporation, minimum inflow, average outflow, peak outflow, average inflow, reservoir level, discharge and minimum outflow. The results of the cumulative contributions show that December has the highest elements contributing to the explanations of electricity generation. Generally, months of high runoff are known to have lower numbers of elements contributing to electricity generation. This suggests that reservoir management in dry period is more challenging. Considerably, [13] investigated the impacts of decadal precipitation variations on reservoir inflow, flood releases and pool elevation in Fortcobb reservoir, at Central Oklahoma. The study shows that watershed runoff, reservoir inflow and flood releases are highly sensitive to decadal precipitation variations. Yet, the only reservoir operation that appears to be impacted by decadal precipitation variations is the frequency of flood release activities [14]. So, it is known that high reservoir inflows during wet periods leads to an increase in flooding that affects power generation.

5. Conclusions

Assessing the impact of climate variability on reservoir-based hydro-power generation in Jebba dam, Niger State, Nigeria has revealed the extent at which climate variables could influence hydro electricity generation. The interactions of rainfall, temperature and evaporation have shown that they are key factors to reservoir inflow and outflow of water resources. The finding establishes that the Jebba reservoir does have inflow in all seasons, resulting from constant upstream flow from Kainji Reservoir which sometimes brings about flooding. The inflow and outflow of reservoir which are determined by climatic variables of rainfall, temperature and evaporation have the capacity to influence electric power generation. The study unveiled the trend and fluctuation of electricity alongside the trends of climatic variables showing that hydro electric power generation is a phenomenon of the climate. The practice of climate change as a contemporary global phenomenon which has strong influence on power generation should be given adequate attention in order to survive in the Nigerian hydroelectric sector. The Nigerian government should review the current water resources and drainage basin management framework that will consider the present stage of development. Some of non-hydrological factors such as maintenance and spare parts problems, inadequate funds, human resources, and policy issues should be considered to avoid system collapse as in the case of the faulted sixth turbine. Therefore, ability of the government to improve the reservoir water capacity considering the current climate reality will accelerate electricity output during period of water scarcity.

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2100”, Department of Economic and Social Affairs.


REVIEW
Urban Rejected Water Reuse in Agriculture for Irrigation in Major Cities of India: A Synoptic Review

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ABSTRACT

Indiscriminate and rapid urbanization without sufficient infrastructure to manage huge domestic sewage (urban rejected water) generated by urban centers posing serious threats to different ecosystems in many places across the world. On the other hand, the downstream of urban centers facing an acute shortage of water for irrigation. In recent years reuse of urban waste water is being increased in many countries including India irrespective of adverse impacts on other ecosystems. The present study has provided a synoptic review on urban rejected water reuse for irrigation in the major cities of India with a special focus on banks of the Musi river basin in South India where huge wastewater irrigation is being practiced in the world in comparison with global waste water irrigation practices. In all the cases major contaminants namely fecal coliform, nitrates, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Dissolved Oxygen (DO) are found in water and with increased soil and groundwater salinity on long term use. The review indicated that there a large scope to intensify the irrigation with proper treatment of wastewater. The study also suggested to understand the impacts of rejected water reuse impact on soil-water-food chain and also emphasizes the need for the establishment of sufficient ETPs to minimize the adverse impacts and also to protect hydro-agro ecosystems.

1. Introduction

In recent years, wastewater irrigation is being increased especially in the case of destitute countries where farmers economically interesting peri-urban interfaces and hardly able to find unpolluted surface water sources \cite{1,2,3}. Water reuse could be an option in water-scares regions in the world for supplying reliable water for different applications where high-quality water is not required. Consequently, freeing up limited potable water sources conserving the freshwater resources, while reducing the effluent discharges into the receiving waters \cite{4}. The land application of wastewater for disposal is an indispensable solution and agricultural use was utilized first in European cities and later in USA \cite{5}. In recent years, interest in water reuse is growing steadily not only in relatively water deficient countries (e.g. Greece, Portugal), but also in highly populated Northern European States such as Belgium, France,

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U.K and Germany, as well as in tourist coastal areas and islands [6]. Currently, water reclamation and reuse projects were being planned and implemented all over the world. Recycled water is presently used for almost any purpose including potable use [5]. It is projected that 700 million cubic meters per year (Mm³/yr.) of treated wastewater were directly reclaimed and used as an alternative source of water in Europe in 2004 [7]. In many countries, the reuse of (usually treated) wastewater is an important strategy to cope with fresh water crises [8]. Demonstrated case studies on recycled domestic wastewater in various countries including Australia, Asia, United States, India, Latin America, Europe, the Middle East, and Africa is already available [9,10,11]. These studies may be the best examples for planning the future reuse of urban rejected water in various parts of the world [12]. Water scarcity problems are common in the arid and semiarid regions, which include the highly populated regions of Asia particularly India, China, the United States, and most of the Middle East. Wastewater reuse is an alternative to increase available water supplies [13]. Land application of wastewater is widespread phenomena, having both beneficial or detrimental effects depending on the geographic region and the type of wastewater produced and represents around 10% of the total irrigated area worldwide, although varying widely at local levels [14]. Reuse of wastewater in agriculture can be a sustainable solution encouraged by various countries to face water scarcity worldwide with robust management practices, such as the application of suitable treatment technologies and irrigation practices that can be beneficial while minimizing risks [15].

On the other hand, untreated wastewater irrigation is associated with numerous environmental problems including soil salinization, reduced soil hydraulic conductivity, reduced crop yield, and surface/groundwater resources contamination, the wild life, and the food-chain and eventually the prevalence of diseases [16,17,18]. Further, reuse of wastewater for agriculture causing microbial contamination in the edible parts of vegetables and accumulation of heavy metals, and Pharmaceuticals presence in the wastewater are a growing global concern [19]. Though treated wastewater is augmenting irrigation water supplies, there has been great concern about associated health risks and environmental impacts [20]. India is one of the fastest developing countries with an alarming rate of rise in urban population facing severe water scarcity in terms of its quality and quantity. At the same time urban centers producing huge amounts of domestic sewage that would have great potential for reuse to reduce some of the water stress for irrigation that can produce an agriculture-based economy in peri-urban areas. The present study has reviewed domestic waste water production and its reuse in the ten major urban cities of India and its consequences on the environmental health of different ecosystems with a special focus on Musi river basin where the highest domestic sewage is being reused for irrigation in Hyderabad, India.

2. Study Area and Methodology

In the present study, we have provided a synoptic review of existing wastewater reuse practices in different countries in comparison with India based on published literature. All relevant literature is properly cited and provided as a list of references. It is also provided the wastewater reuse impacts on different ecosystems that include surface water, soils, groundwater, and corps in the major cities of India with a major emphasis on Hyderabad city situated on the banks of Musi river in South India. The water source for Hyderabad city met from different sources from external river basins. The Hyderabad Metropolitan Water Supply & Sewerage Board (HMWS&SB) is responsible for the supply of freshwater and management of sewage water. HMWS&SB is drawing 172 million gallons a day (mgd) of Godavari water at the Yellampally barrage and 270 mgd of Krishna water from Nagarjun Sagar reservoir, combined with a total quantity of 442 mgd (equivalent to 1675 MLD) of fresh water is supplied for the population of Hyderabad city in the state of Telangana, India [21]. The urban rejected water (sewage) from Hyderabad flows to the Musi river. In 2020, it was reported that nearly 700 MLD of the wastewater (i.e. 40%) has been reused out of total wastewater produced from the both domestic and industrial origin in and around Hyderabad city (Figure 1). About 10,000 ha, of paddy rice crop (Oryza sativa) and 2100 ha, of paraggrass (Brachiaria mutica) are being irrigated with wastewater in downstream of Hyderabad. Paraggrass is perennial crop and grows well using the nutrients carried in the stream under warm, moist and fertile conditions. Availability of wastewater enables farmers to harvest Para grass throughout the year or to produce two rice crops kharif and rabi annually for their livelihood [22]. In the present, we also have collected water, soil and groundwater samples in the Musi catchment. The daily water requirement and produced waste water are estimated by using the following formulae.

Quantity of water required daily = [Total Population] X [liters per capita per day (lpcd)] (MLD) -Equation (1)

Quantity of wastewater generated daily = 80% of the fresh water used (MLD) - Equation (2)

Cost of the Treatment Plant (STP) in lakhs INR = Quantity of wastewater in MLD X 80 lakhs INR - Equation (3). Estimated Cost for the Treatment of one million liters (1 MLD) of wastewater = 80 Lakhs [23]. The popula-
tion data are obtained from world statistical data [24].

3. Global Wastewater Reuse Practices

Various cities in India and China are reusing urban sewage water after partial or full treatment for various applications of non-potable use such as farm forestry, peri-urban irrigation, horticulture, toilet flushing, industrial use for cooling towers, fish culture, producing vermicompost, gardening including parks, resorts and golf course. China treats 95% of total wastewater discharged by municipal wastewater treatment plants (WWTPs), around 4.98 giga cubic meter. The treatment process involves primary, secondary and tertiary treatment in both countries, in addition to this China uses novel wastewater treatment technology, such as Anaerobic Ammonia Oxidation to treat the wastewater [25,26]. Singapore reuses urban rejected water after treatment for indirect potable water called NEWater. In this process treated sewage water combines with nutrient-rich reservoir water, purified again, and filled into bottles. Today, around five percent of tap water in Singapore comes from NEWater [27]. Singapore’s NEWater pre-treatment includes removal of debris, uses primary and secondary sedimentation tanks and bio-reactors, ultrafiltration (UF), reverse osmosis (RO), and UV disinfection [28]. In various parts of USA, wastewater is reused for irrigation (both agricultural and landscape), recharge of aquifers, seawater barriers, industrial applications, dual-distribution systems for toilet flushing, residential irrigation, golf course irrigation, groundwater recharge or indirect potable reuse, wetlands, and other urban uses. In California, microfiltration, reverse osmosis, and ultraviolet irradiation (UV) are the treatments prior to groundwater recharge [29]. Japan reuses around 215 million cubic meter per year recycled urban sewage water for different environmental applications including snow melting, irrigation, landscapes, direct supply industrial use, industrial water system. The sewage water is treated with highly advanced water treatment using a membrane bioreactor system in Japan. Tokyo reuses to meet environmental flow requirements of rivers after treatment with UF method, recreational use applies RO method, and toilet flushing treated with biological filtration and ozone followed by membrane treatment method and clean or wash water with ozone treatment [30]. In Australia, the Sydney suburb of Rouse Hill wastewater treatment plant treating 4.4 million liters per day of wastewater for reuse, with coagulation, flocculation, filtration, and disinfection, initially including ozonation but subsequently with UV irradiation and super-chlorination treatment techniques [31]. Windhoek, situated in the center of Namibia, South Africa uses recycled water for drinking water purposes due to a lack of surface and groundwater supplies, here wastewater treatment includes primary settling and anaerobic digestion with drying beds. To produce high-quality water for both drinking and irrigation biofilter system was integrated into the activated sludge system [32]. Reuse of urban rejected water without proper treatment may have adverse negative impacts on human health and the environment. To meet quality criteria to minimize the risks, US Environmental Protection Agency (EPA) has set the guidelines for wastewater reuse. The main purpose of the EPA Guidelines for water reuse is to provide supporting information for the benefit of regulatory agencies to implement water reclamation for non-potable use of urban, industrial, and agricultural purpose and augmentation of potable water supplies through indirect reuse without any major adverse health and environmental risks [33,34]. The comparative reuse water quality standards of various countries are shown in Table 1, which could be useful for regulatory authorities elsewhere.

4. Results and Discussion

Direct use of urban rejected water reuse is restricted in recent decades to protect public health and the environment. Many countries are not able to afford for proper treatment of waste water due to heavy investments involved in the treatment depending on the volume of the wastewater produced and the number of treatment stages [35]. Irrigation with reclaimed water has shown a favorable response on crop growth and yielded acceptable product qualities however, the reuse of improperly treated waste water in irrigation may cause environmental deterioration, pollution in the irrigated area, and groundwater contamination, decrease in soil quality, and posed risks to human health [36]. Wastewater application is associated with an increased risk of various infectious diseases due to high pathogen levels and many other contaminants concentrations found in wastewater [32]. Despite the negative impacts of waste water reuse, Florida and California of USA is efficiently utilizing the reclaimed water for the past 50 years by imposing restrictions more stringent than World Health Organization (WHO) guidelines [9]. All developed countries are following stringent regulations while reusing urban wastewater. However, there are no stringent regulations or comprehensive policies on wastewater reuse exist in India. Due to this limitation and without separate wastewater reuse policies, it is estimated that 75 percent of the total wastewater produced in India discharged without treatment [37].

As the overall demand for water increases with a rise in population there will be a definite increase in the quantity of wastewater produced and its overall pollution load. In
**Table 1.** Irrigation water quality standards for wastewater reuse in agriculture used by various countries

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameters</th>
<th>India</th>
<th>South Korea</th>
<th>WHO</th>
<th>US EPA</th>
<th>Cyprus</th>
<th>France</th>
<th>Greece</th>
<th>Italy</th>
<th>Israel</th>
<th>Spain</th>
<th>Saudi Arabia</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fecal coliform (count/100 ml)</td>
<td>≤ 500 (MPN)</td>
<td>≤ 200 (MPN)</td>
<td>≤ 10000 (cfu)</td>
<td>≤ 200 (cfu)</td>
<td>≤ 1000 (MPN)</td>
<td>≤ 2000 (cfu)</td>
<td>≤ 200 (cfu)</td>
<td>≤ 100 (cfu)</td>
<td>≤ 1000 (cfu)</td>
<td>≤ 1000 (cfu)</td>
<td>≤ 1000 (cfu)</td>
</tr>
<tr>
<td>2</td>
<td>Turbidity (NTU)</td>
<td>≤ 5</td>
<td>≤ 5</td>
<td>≤ 2</td>
<td>≤ 2</td>
<td>≤ 10</td>
<td>≤ 5</td>
<td>≤ 10</td>
<td>≤ 5</td>
<td>≤ 10</td>
<td>≤ 5</td>
<td>≤ 10</td>
</tr>
<tr>
<td>3</td>
<td>Suspended Solids (mg/L)</td>
<td>≤ 30</td>
<td>≤ 45</td>
<td>≤ 35</td>
<td>≤ 35</td>
<td>≤ 10</td>
<td>≤ 35</td>
<td>≤ 10</td>
<td>≤ 35</td>
<td>≤ 10</td>
<td>≤ 35</td>
<td>≤ 10</td>
</tr>
<tr>
<td>4</td>
<td>BOD mg/L</td>
<td>≤ 30</td>
<td>≤ 30</td>
<td>≤ 25</td>
<td>≤ 25</td>
<td>≤ 20</td>
<td>≤ 10</td>
<td>≤ 20</td>
<td>≤ 10</td>
<td>≤ 20</td>
<td>≤ 10</td>
<td>≤ 20</td>
</tr>
<tr>
<td>5</td>
<td>COD mg/L</td>
<td>≤ 100</td>
<td>≤ 100</td>
<td>≤ 60</td>
<td>≤ 100</td>
<td>≤ 100</td>
<td>≤ 100</td>
<td>≤ 100</td>
<td>≤ 100</td>
<td>≤ 100</td>
<td>≤ 100</td>
<td>≤ 100</td>
</tr>
<tr>
<td>6</td>
<td>Odor</td>
<td>Unobjectionable</td>
<td>Pleasant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Total Nitrogen (mg/L)</td>
<td></td>
<td></td>
<td>2 - 6</td>
<td>≤ 15</td>
<td>≤ 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Total phosphorus, mg/L</td>
<td></td>
<td></td>
<td>≤ 1</td>
<td>≤ 1</td>
<td>≤ 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Intestinal nematodes (count/L)</td>
<td></td>
<td></td>
<td>≤ 1</td>
<td>≤ 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>≤ 1 (/10L)</td>
</tr>
<tr>
<td>10</td>
<td>pH</td>
<td>6 - 8.5</td>
<td>5.8 - 8.5</td>
<td>6 - 9</td>
<td>6 - 9.5</td>
<td>6 - 9.5</td>
<td>6 - 9.5</td>
<td>6 - 9.5</td>
<td>6 - 9.5</td>
<td>6 - 9.5</td>
<td>6 - 9.5</td>
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</tr>
<tr>
<td>11</td>
<td>EC (µs/cm)</td>
<td>≤ 2250</td>
<td>≤ 2000</td>
<td>≤ 1500</td>
<td>≤ 1400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>DO</td>
<td>≥ 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

(Source: Hanseok Jeong et al., 2016 and Al-Jasser, 2011)

**Table 2.** Current and projected wastewater generation and treatment capacities with treatment costs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyderabad (Telangana)</td>
<td>10.27</td>
<td>2068</td>
<td>1700</td>
<td>930</td>
<td>770</td>
<td>13.00</td>
<td>1950</td>
<td>250</td>
<td>7440</td>
</tr>
<tr>
<td>Vellore (Tamil Nadu)</td>
<td>0.58</td>
<td>86</td>
<td>69</td>
<td>31</td>
<td>38</td>
<td>0.71</td>
<td>107</td>
<td>38</td>
<td>248</td>
</tr>
<tr>
<td>Bangalore (Karnataka)</td>
<td>12.77</td>
<td>2250</td>
<td>1800</td>
<td>1080</td>
<td>720</td>
<td>16.59</td>
<td>2000</td>
<td>200</td>
<td>8640</td>
</tr>
<tr>
<td>Delhi</td>
<td>31.18</td>
<td>4500</td>
<td>3600</td>
<td>885</td>
<td>2715</td>
<td>39.81</td>
<td>4780</td>
<td>1180</td>
<td>7080</td>
</tr>
<tr>
<td>Panipat (Haryana State)</td>
<td>0.56</td>
<td>95</td>
<td>77</td>
<td>7</td>
<td>7</td>
<td>0.70</td>
<td>91</td>
<td>14</td>
<td>56</td>
</tr>
<tr>
<td>Phagwara (Punjab)</td>
<td>0.12</td>
<td>30</td>
<td>24</td>
<td>7</td>
<td>14</td>
<td>0.14</td>
<td>30</td>
<td>6</td>
<td>56</td>
</tr>
<tr>
<td>NEERI, Nagpur (Maharashtra)</td>
<td>2.94</td>
<td>680</td>
<td>524</td>
<td>44</td>
<td>480</td>
<td>3.61</td>
<td>605</td>
<td>81</td>
<td>352</td>
</tr>
<tr>
<td>Pune (Maharashtra)</td>
<td>6.81</td>
<td>1350</td>
<td>1080</td>
<td>620</td>
<td>460</td>
<td>8.63</td>
<td>1295</td>
<td>215</td>
<td>4960</td>
</tr>
<tr>
<td>Kolkata (West Bengal)</td>
<td>14.97</td>
<td>2246</td>
<td>1796</td>
<td>793</td>
<td>1003</td>
<td>17.97</td>
<td>2156</td>
<td>360</td>
<td>6344</td>
</tr>
<tr>
<td>Chennai (Tamil Nadu)</td>
<td>11.24</td>
<td>1985</td>
<td>1588</td>
<td>861</td>
<td>727</td>
<td>14.12</td>
<td>1938</td>
<td>350</td>
<td>6888</td>
</tr>
<tr>
<td>Mumbai (Maharashtra)</td>
<td>20.67</td>
<td>3750</td>
<td>3000</td>
<td>1002</td>
<td>1998</td>
<td>25.12</td>
<td>3530</td>
<td>550</td>
<td>8016</td>
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</tbody>
</table>

DOI: https://doi.org/10.30564/hsme.v3i1.3208
India, various cities practicing wastewater irrigation and it is important to understand their impacts on different ecosystems. The present and projected population, water requirement, and wastewater generation for major Indian cities are provided in Table 2. The table shows that produced wastewater is going to increase that demands more investments.

These cities using untreated or partly treated wastewater for irrigation. Many studies have been carried out to assess the impact of wastewater reuse on soil, water, and crop ecosystem. The summarized results for major Indian cities are provided in Table 3.

The complied results indicated sewage effluents and groundwater in Delhi, India shows there was no significant difference in pH of sewage effluent and groundwater. However, significant seasonal variation in pH of sewage effluent is observed. The electrical conductivity (EC) of groundwater was higher as compared to that of sewage effluents.

This may be ascribed to the leaching of salts from soil sodium due to the long-term use of sewage effluents that enriched groundwater with salts. There were no significant differences between metal and metalloid content in sewage and groundwater indicating that the groundwater in this area was contaminated with sewage irrigation. The study in Nagpur city reported that the organic carbon values in sewage water irrigation are higher than well water indicating sewage irrigation aids to improve in fertility status of soil. It is reported that a significant improvement on fertility status of soil for available N, P and K. This indicates that sewage water irrigation provides the essential nutrients to the crops and significant improvement in fertility status of soil with respect to micronutrient. The metals Fe, Mn, Zn, Cu, Pb, Ni, and Cd after harvest were found to be slightly higher than that of well water however, they are within the desirable limits compared to pure sewage water. The use of sewage increased crop production compared to irrigation with well water. On the other hand, the indiscriminate long-term use of sewage effluent for crop production resulted in the con-

<table>
<thead>
<tr>
<th>City Name</th>
<th>Samples</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>S</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Ni</th>
<th>Pb</th>
<th>Cd</th>
<th>Cr</th>
<th>As</th>
</tr>
</thead>
</table>
| KES DELHI 
(Ramu et al., 2016) | Sewage effluents (mg/L)  | 47.1 | 3.41 | 18.5 | 56.8 | 6.29 | 3.58 | 421 | 31.8 | 7.59 | 0.16 | 0   | 1.01 | 8.67 |
|                           | Ground water (mg/L)  |
|                           | 36.7                | 0.67 | 6.25 | 37.8 | 3.65 | 2.95 | 392 | 16.5 | 3.46 | 0.01 | 0.02 | 1.39 | 7.96 |
| Nagpur (India) 
(Singh et al., 2012) | Sewage water (mg/L)  | 0.31 |     | 2   | 24  | 83  | 22  | 4.1 | 7.5 | 2.1 |
|                           | Well water (mg/L)   | 0.18 |     | 2   | 1.2 | 18  | 16  | 1.5 | 4.5 | 0.6 |
| Panipat City 
(India) 
(Pawan et al., 2013) | Effluent (mg/L)     | 0.242 | 0.326 | 0.356 | 0.17 | 0.03 | 0.404 | 0.01 |
|                           | Ground water (mg/L) | 0.153 | 0.384 | 2.303 | 0.4 | 0.1 | 1.284 | 0.01 |
|                           | Soil (μg/g)         | 13.13 | 26.63 | 44.08 | 9.9 | 7.96 | 42.36 | 1.93 |
|                           | Soil sample Station -1 (mg/kg) | 37.2 | 5.4 | 126 | 30.6 | 4.8 | 7.2 | 1.2 |
|                           | Soil sample Station -2 (mg/kg) | 30.6 | 3 | 150 | 60 | 3 | 7.8 | 3 |
| Bengaluru Soils 
(Jayadev and Puttaih, 2012) | Soil sample Station -3 (mg/kg) | 15.6 | 0.6 | 186 | 72 | 5.4 | 9 | 2.4 |
|                           | Soil sample Station -4 (mg/kg) | 18 | 9 | 180 | 28.8 | 6 | 5.4 | 0.6 |
|                           | Soil sample Station -5 (mg/kg) | 21 | 21.6 | 199.2 | 30.6 | 19.2 | 1.2 | 24 |

DOI: https://doi.org/10.30564/hsme.v3i1.3208
concentration build-up that may become phytotoxic that may cause clinical problems both to animals and human beings consuming these metal-rich plants in India. Groundwater in Panipat showed that the concentrations of metals like Pb and Fe in excess quantity (0.74 and 2.76 mg/L) respectively, among these Fe, Pb, Cu values found were at a high level due to their cumulative and adsorptive properties in the soil after repeated irrigation by contaminated groundwater. Cadmium and Zinc were found minimum due to their weak adsorptive nature in soil.

In Punjab, the reuse of wastewater impact on soil and groundwater is extensively studied. The chemical concentration in soils was analyzed with the application of groundwater and sewage water. Sewage application on soil after 10, 15 and 20 days was analyzed. They reported that both opportunities and problems exist in using sewage water for irrigation. Wastewater irrigation helps in water conservation and nutrient recycling, hence, reducing the demands of freshwater. But variation in pH of soils is observed when compared to groundwater irrigations with soil irrigated with the sewage water. The value of Nitrogen (N) and Phosphorus (P) is increasing till day 10 but decreases thereafter and the value of Potassium (K) is increasing till day 15 and decreases thereafter. Organic carbon (OC) is decreased till day 10 but increases from day 10 to day 15 and gradually decreases till day 20. The use of wastewater is proved to be beneficial for 10 to 15 days in the selected crops. The application of domestic wastewater increased the crop yield compared to irrigation with groundwater. In another case study carried out in Vrishabhavathi River, Bangalore, Karnataka, revealed that, the concentration of heavy metals in soil was in the order of Fe>Mn>Zn>Cu>Ni>Cr>Pb. Cadmium was below the detectable limit. Cadmium was below detectable level in all vegetable samples. In the water and sediment samples from four different stations of Adyar River at Tamilnadu were collected. The concentration of heavy metals in river water and river sediments was determined and results indicated that the concentration of heavy metals found in river water was lower than the sediment samples of River Adyar that are within drinking water standards. The wastewater samples were collected at two locations in different periods in an industrial area situated in the southwest of Vellore district, Tamilnadu, India. During four seasons for analysis. The results revealed that the parameters are within the allowable limit for agricultural usage. Therefore, it affects the surface water, groundwater, and soil surrounding area. However, bore wells located close to the industrial area show TDS, alkalinity, sodium, calci-

**Figure 1.** Different chemical concentrations in surface water from 2011 to 2018 at three different locations in Musi river basin (Data Source: TSPCB)
um, potassium, chloride sulfate, and Hardness exceeds the permissible limit for drinking purposes by [45]. The following sections are explained the impact wastewater reuse on soil, water, and crops in the Musi catchment in detail.

4.1 Wastewater Impact on Surface Water Quality

The time series analysis data of physico-chemical parameters of surface water from 2011 to 2018 in the upstream named as Gandipet (OsmanSagar lake), Hyderabad which is fresh water source that supplies part of Hyderabad city drinking water need indicates the DO, COD, BOD, Nitrate-N, Phosphate, Boron, fluoride, sodium absorption ratio values are within drinking water standards [45] and irrigation water standards prescribed by Indian Standards (IS) [47]. Hardness values in 2014, 2015 and 2016 exceed the permissible limit for irrigation, fecal coliform, and total coliform value found in 2011, 2012 exceeded the permissible that could be due to domestic waste water flows with insufficient fresh water for dilution (Figure 1).

When it goes downstream at Nagole and Pratapsingaram, the analysis results revealed that total coliform and fecal coliform are very high concentrations that show the high mixing of domestic water with surface water. Chloride, Hardness, Sodium, Total Suspended solids (TSS), Potassium values also more than the permissible limit of BIS (2012) irrigation standard downstream of the area. This indicates the strong sewage comprising of suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms. The dissolved oxygen (DO) values less than the minimum prescribed value of BIS (2012) irrigation standards are undesirable and indicates that low oxygen level available for living organisms (Figure 2). (DO) primarily results from excessive algae growth caused by phosphorus and low DO value in the water system causes a threat to aquatic life. Fecal Coliform and total coliform values found in 2011, 2013, and 2018 exceeded the permissible limit. Biochemical oxygen demand (BOD) values found in 2011, 2012, 2013, 2015, 2016 and 2017 exceed the permissible limits of BIS (2012) irrigation standard (Figure 1). The sodium absorption ratio (SAR) value found in 2011 exceeds the permissible limit of BIS (2012) irrigation standard.

4.2 Wastewater Impact on Groundwater Quality

In the Musi river basin, huge groundwater is also being pumped out that is more than natural recharge, as
result groundwater wells are less productive or dried out. Hence, to supply the irrigation needs of the area, farmers are using wastewater in downstream. As presented in the previous section salinity of surface water is being increased over the years. When high saline water is applied with other pollution loads on the ground-surface, soil and groundwater quality may have deteriorated on long-term use. The water quality results for two years 2016 and 2020 of groundwater Peeradiguda are shown high TDS and Sulphate values which are more than drinking water standards of WHO, 2011 (Figure 3). The BOD value in the year 2020 exceeds the acceptable limit. The higher values indicate that the leaching of the Musi river water into the groundwater storage which receives heavy loads of domestic and industrial waste produced in Hyderabad. Sulfate value in the year 2016 exceeds the acceptable limit [48,49]. Sujatha has reported the high inorganic matter and high turbidity in groundwater samples which are commercial, industrial or domestic wastewater, and alkalinity and sulfate it is due to discharge of domestic sewage which contains detergents, sulfates induces the formation of sulfuric acid, Hydrogen sulfate [48]. A high level of sodium and salinity hazard values affects all types of vegetables and paddy rice grown in this area. Sodium and chloride present in canal water posed toxicity problems to plants [50].

4.3 Wastewater Impact on Soil Quality

Soil and fodder crop samples were collected for two

Figure 4. Chemical concentrations in soil in four different villages along the Musi (Source: Raju et al., 2020).

Figure 5. Chemical concentrations in water, soil and crops at Gourelli Village in the Musi catchment
seasons Kharif (2012) and Rabi (2012-13)\(^\text{(51)}\). At four villages along the Musi river corridor, namely 1. Peerzadiguda 2. Parvathapuram 3. Prathapsingaram 4). Gourelli in Hyderabad where, wastewater irrigation is being used to grow paddy, fodder grass and vegetables (Figure 4). The fodder grass was supplied to feed the living stock mainly cows and buffalos. The soil and fodder samples were analyzed for pH, Electrical conductivity, Organic carbon, Nitrogen, Iron, Manganese, Zinc, Copper and the heavy metals Lead, Cadmium, Nickel, Cobalt, and Chromium and compared with non-polluted area. The results of at four villages that the pH of soil samples is slightly neutral to basic and cadmium (Cd) value of soil samples in rabi season was exceeding the permissible limit\(^\text{(51)}\). This is due to the no rains in rabi season, lack of dilution, cadmium concentration was high in wastewater applied to soil for growing crops. The plant’s soil pH increases consequently, its food’s pH value becomes too high, due to this the plant’s ability to absorb certain nutrients is disrupted. Long-term exposure to cadmium through the air, water, soil, and food leads to cancer and organ system toxicity such as skeletal, urinary, reproductive, cadmium contamination causes cancer to human beings and animals. The remaining parameters, Electrical conductivity, Organic carbon, Nitrogen, Iron, Manganese, Zinc, Copper, and the heavy metals Lead, Chromium, Nickel, and Cobalt in soils of Peerzadiguda of both the seasons were within the permissible limit. We also have analyzed chemical parameter concentration of soil, water (river, canal, and borewell), and fodder, that results say that groundwater is not affected by heavy metals (Figure 5). However, soil salinity in terms of chloride is very high and magnesium also very high due to wastewater application. The long-term use of untreated wastewater may impact soil salinity that may lead to water logging.

**4.4 Wastewater Effects on Crop Quality**

Soil and Forage grass (Paragrass) samples were collected along 8 km stretch of the Musi River, including 2 km on either side of the river, Hyderabad India. The samples were analyzed and results of zinc (zn) (164.2-212.4 μg/g), chromium (cr) (20.2-36.7 μg/g), copper (cu) (15.7-29.6 μg/g), nickel (ni) (10.7-18.3 μg/g), cobalt (Co) (3.7-7.1 μg/g) and lead (Pb) (66.7-101.7 μg/g) are reported. The Permissible values for Zn range between 1-100 (μg/g), Cr -0.03-14 (μg/g), Ni -0.02-5 (μg/g), Co - 2-10, (μg/g), and Pb range in between 5-10 (μg/g) respectively\(^\text{(52)}\). The analysis results indicated that the Zinc, Chromium Copper, Nickel Cobalt, and Lead values exceed the permissible limits of drinking water and irrigation water values prescribed by BIS (2012) standards. This is due to the disposal of industrial effluents containing a high concentration of zinc, Chromium, Copper, Nickel Cobalt in Musi wastewater which is used for irrigating the fodder grass and other crops. Lead pollution occurs due to the dumping of used electric batteries into soil and water bodies and from automobile exhausts hence, regular monitoring of metal concentration in soil is imperative\(^\text{(52)}\). However, in the present our analysis reports at Gourelli Village show that all chemical concentrations were within acceptable limits of BIS, 2012\(^\text{(53)}\) (Figure 5).

It is reported that the total irrigated water requirement for the whole Musi catchment is about 1235 Mm\(^3\)\(^\text{(54)}\). Due to overexploitation of groundwater, aquifers were dried and wells are less or unproductive. At the same huge waste water is available to the downstream of Hyderabad at the of 1700 MLD now and it is projected to be 1955 MLD by 2031. Hence, proper treatment and reuse of the domestic wastewater can reduce stress on the aquifer and can increase the economy of the farmers. The above studies reported both positive and negative impacts of waste water reuse for irrigation and hence before introducing it into the irrigation system, the quality of reused water should be ensured to control the impacts of long-term usage. The level of treatment may adopt based on the nature of contaminants and usage of water considering the global wastewater reuse practice mentioned above sections.

**5. Conclusions**

The integration of improper treatment of urban domestic rejected water in irrigation will have adverse impacts on many ecosystems such as soil salinity, waterlogging, and contamination of both groundwater and surface water. The contaminated water can damage the wildlife ecosystem and the food-chain and eventually the prevalence of diseases. In order to effectively utilize the huge quantity of wastewater to reduce the water stress in the urban catchments, a proper treatment mechanism should be established. After ensuring its quality, it can be integrated into water resource planning and management for beneficial reuse in irrigation. It is highly recommended that reuse of wastewater for irrigation or any other requirements after reaching the required quality standards prescribed by US EPA or local country guidelines to minimize the potential risks to the public health and environment.

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tion water.


ARTICLE

Soil-water-security Systems of Agriculture and Adaptation to Changes of Climate

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ABSTRACT

In article the expediency of application of methods of protection soils from erosion and in general principles of the antierosion organization of territory of land tenure for adaptation of territories to changes of a climate is considered. The expediency of updating of these methods in connection with new results of supervision for runoff on slopes and the new purposes of their application is shown. In particular, it is shown, that antierosion constructions need to be placed above a place of concentration of a runoff, instead of on it as the probability of destruction of a construction in this place is great. Application the soil-water-security systems of agriculture provides regulation of a microclimate of territory (reduction of warming up of a surface), allows to lower peak of a high water from downpours, translating a part of a superficial runoff in intrasoil and underground and to these to prevent losses from them including loss of a fertile layer of soils, saturation by a moisture of a zone of aeration favorably influences development of forest vegetation and agricultural crops.

1. Introduction

Changes of climate of last years mentioned practically all corners of globe, polar ices thaw, desertification of steppe territories, etc. are observed [4,12,16,26]. In documents WMO, FAO etc. appeals to necessity of adaptation of territories to changing conditions of environment for maintenance, both food safety of the population, and personal and their material security from spontaneous displays of a changing climate [4,6,17,38,39].

Among spontaneous displays of change of a climate name non-uniform redistribution of atmospheric precipitation in a year and increase in extremeness of their loss [14,26,29,37], i.e. precipitation become more intensive, and their loss leads to formation of short-term floodings of extensive territories and is frequent to a loss of property, and sometimes and to human victims. Non-uniformity of loss of precipitation in time also results, frequently, in a loss of property as can lead to loss of a crop, the aggravation of fytosanitory conditions in region, etc. For steady functioning geosystems needs regulation of distribution of heat and a moisture on territory, creation of a favorable microclimate of adjacent territories will promote stability of all geosystem as a whole. The mechanism, capable adjust spontaneous displays of changes of a climate the organization of territory of land tenure (agro-, forest-

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hydro-land improvements, rational and coordinated with a lay of land, accommodation of roads, fields, and other boundaries), widespread on all territory of a catchments basin of a problem zone can to act. About effective use of the organization of territory of land tenure in prevention of erosive processes and regulation of a water mode of territory not few works \([9,12,27,28,30,31]\) are already written and works according to similar recommendations were conducted on separate parts of problem territories. Even are available more than the centenary experiences incorporated still V.Dokuchaevym in Stone steppe and on stream (arroyo) catchment of the river Derkul (inflow of the river Severski Donets) with application of water-retaining dams on the hollows running into a beam, with landings large forests and forests strips which exist and to this day, creating a special microclimate in initially steppe territory which have been strongly cut up by ravines, and keeping natural kinds of plants and animals, that already seldom meet on the steppe files located by a number at practically full turfs before existing ravines. However, for full scope of problem zones yet does not suffice either means, or aspirations. Changes of climate, anyhow, nevertheless compel to search for decisions, and these decisions are in complex use of the saved up experience.

Stabilizing influence on geosystem render, as actions on protection of ground against erosion (regulation of carry of heat and energy in geosystem), and optimization of territory of land tenure concerning preservation of a necessary level of humidifying of soils, maintenance of satisfactory fytosanitary conditions, etc., actions on a layout of the occupied places for prevention of floodings and formation of streams of the water destroying an infrastructure of settlement, etc. of Action of constant action (shaft-ditches, roads, forests strips, etc.) interrupt concentration of a superficial runoff and promote translation of a superficial runoff in intrasoil than slow down promotion of water to places of unloading - to the rivers, lakes and the seas. It promotes decrease in peaks of high waters, them flattening in time and provide a soil feed of the rivers that is important for functioning water ecosystems in low-water. Importantly there is a selection of specific parameters of the actions entering into the organization of territory, capable to provide necessary stability.

2. Methods and Materials of Researches

The analysis of references, materials of long-term supervision over formation of a runoff from slopes from downpours was spent and at snowmelts \([8-11]\) with the purpose of an opportunity of application of existing technologies of the organization of territory of land tenure, including antierosion, to adaptation of territories to change of a climate, and also their some updating on the basis of natural supervision.

3. Results of Researches

Among the basic antierosion actions now allocate hydraulic engineering (shaft, shaft- ditches, terraces, etc.) and agrotechnical (agricultural background, their alternation on a slope, processing of slope). For construction of hydraulic engineering, water-carrying and other constructions on slopes calculation of the basic hydrological characteristics of time water-currents (a runoff, washout and the maximal depth of water) on slopes, mostly, on the basis of the long-term provided climatic sizes of sediments, temperatures, etc. Depending on speeds of running off or volume of a runoff is spent and (or) depending on volume of washed off soils from slopes places where the stream reaches their critical sizes are defined, and distances between flow regulation boundaries are appointed. Last way is considered the most proved since allows to estimate at once results of soil-protective system of agriculture and efficiency of various actions.

Distinctions in techniques applied now lays not only in various approximating methods of calculation, but also in distinctions of applied schemes of formation of a runoff and loss.

Schemes of formation of a runoff of water on slopes can be classified on distribution of a layer of water on length of a slope; on character of running off of water on a slope.

On distribution of a layer of water on length of a slope R.E.Horton’s scheme \([22]\): depth of water accrues on length of a slope. Dependence has sedate an appearance: \(h=\alpha L^b\);

A.N.Befani’s scheme \([2]\): depth slope streams depends on a difference between time runoff formation and time sloping lag-time) if time runoff formation exceeds time sloping lag-time depth slope streams essentially increases from a watershed downhill; in this case it is considered, that formation of a runoff on all slope occurs as a full runoff; if time runoff formation is less than lag-time - depth on length of a slope does not change (incomplete type runoff formation).

B) On character of a longitudinal structure of a slope

1) the runoff goes a continuous veil on all surface of a slope (a plane runoff) \([24]\);
2) the runoff occurs mainly in streamlets \([17]\);
3) rill and interrill a runoff \([19]\).

Schemes of formation of washout of a slope are subdivided under the factors, A) factors providing loss; B) on character of a longitudinal structure of a slope; C) on
A) Under the factors providing loss
   1) loss arises, if speed of a stream reaches washing away speed \cite{1,32};
   2) loss arises, if tangents of a pressure reach critical sizes \cite{19};
   3) the zone of increase of intensity of loss of soil on length of a slope is limited by length of a way lag-time “separate section” (divides “ a full runoff ” from “ an incomplete runoff ”) on long slopes \cite{33,36};
   4) fall a slope (carrying out products denudation) occurs up to a place where the stream passes in the stated condition, below on a slope adjournment of sediments \cite{1} (on transporting ability) is observed;
   5) the combination of mechanical and chemical factors of destruction of a surface of a slope, is closer to a watershed a role of chemical factors is more significant mechanical \cite{9-11}.

B) On character of a longitudinal structure of a slope
   1) the slope on length shares on three zones: a belt of absence of erosion, a zone of active erosion and a zone of adjournment of sediments \cite{12,28};
   2) a slope on length can be divided, at least, on 4 zones, 2 from which periodically repeat downhill. The first zone is length of concentration of a runoff here loss is not formed. The second zone - initial length of loss - here depth of loss increases downhill. The third zone is a length of sedimentation of sediments. The fourth zone is length of critical loss. Here there is a catastrophic loss on rather small site of a slope (0,2-1m - depending on character of a water-current and length of a slope). Behind the fourth zone there is an alternation of a zone of sedimentation and a zone of loss \cite{8-11}.

C) On scope of the water-modular area
   1) having washed away mainly in channels of streams;
   2) loss of all surface of a slope;
   3) rill and interrill erosion \cite{19}.  
   Methods of calculation of a runoff on slopes can be subdivided in the next way
   1) use of various updatings of system of equations Saint-Venants \cite{3};
   2) empirical dependences \cite{7,20}.

Practically in all schemes and methods some assumptions and simplifications of representations about formation of a runoff and washout are accepted. Schemes of formation of a runoff and washout differ, notwithstanding what these processes are connected among themselves. Distinctions in features of the arising practical problems connected with склоновыми by processes, compel to resort to various methods of the decision doing accent either on a runoff or on washout.

Frequently in a choice light exposure of the information and development of a question is solving. Most a weak spot is absence of a natural material of researches.

Absence of the regular long-term given supervision over formation of a runoff on slopes was the reason of more thorough study of mathematical models склонового a runoff on the basis of the equations of hydrodynamics \cite{2,21,24,15,34,35}.

Calculations on our materials of supervision for sloping a runoff also show, that communication between the charge of water and its depth rather close, and for downpours factor of correlation of communication above, than for snowmelt while the relative mistake is less for a thawed runoff, nevertheless, it is possible to approve, that communication exists.

Distances between constructions can be appointed proceeding from a condition of achievement a stream of washing away speeds or critical volumes of water, critical silt charge waters, etc. That is the construction is projected in a place of concentration of a runoff where concentration of all power forces of a stream and probability of destruction of a construction is observed is maximal.

Proceeding from supervision over formation a runoff on slopes (as already it is told above by consideration of schemes of formation of washout of a slope on character of a longitudinal structure of a slope a slope on length it was possible to break into some zones it is 1) the zone of concentration of a runoff (Lv), here loss is not observed, 2) the zone of the beginning of loss (Lo), here is observed gradual increase in depth gullies on length of a slope, 3) the zone of adjournment of sediments, here is observed reduction of depth of loss downhill up to its full absence and adjournment of sediments (Lor), 4) the zone of critical loss, here occurs catastrophic loss of soils (Lkp) (Figure 1). Behind a zone of critical loss there is an alternation of zones of adjournment of sediments and zones of critical loss (Figure 2). Borders of zones are dynamical and depend on conditions of formation of a runoff. Frequency and amplitude of fluctuations of depth of loss change year by year and from a downpour to a downpour depending on conditions of formation of a runoff and character of a spreading surface. In a zone of the beginning of loss primary influence on loss is rendered with a chemical component of destroying force of a stream of water, in a zone of adjournment of sediments - dynamic. For a zone of critical loss we can ascertain significant change as silt charge waters, pH waters, and change of the maintenance practically all elements in water. In this zone both chemical and dynamic components are equally significant.
Proceeding from all above told it is necessary to expect, that on the short sites of a slope created at construction of hydraulic engineering constructions on slopes the greatest influence on loss of the chemical component of destroying force of a stream will render.

For forecasting places for a slope where loss of soils is most probable, it is expedient to take advantage of methods of optimization (mathematical programming). As criterion function it is possible to accept the longitudinal area of loss of a slope consisting of pieces above the listed zones. By its optimization on a maximum places on a slope where intensive loss of soils will be observed are defined. By its optimization on a minimum places on a slope where loss will not be are defined. Then the longitudinal area of loss (W) will be defined by criterion function:

$$ W = C_1 L_v + C_2 L_o + C_3 L_{ot} + n(C_4 L_{kp} + C_5 L_{ot}) \rightarrow \min (\max) $$

The system of restrictions includes the following equations:

Restriction on length of a slope:

$$ L_v + L_o + L_{ot} + n(L_{kp} + L_{ot}) = L_s. $$

Restriction on depth of basis of erosion:

$$ L_v + C_2 L_o + C_3 L_{ot} + n(C_4 L_{kp} + C_5 L_{ot}) \leq H L_s; $$

$$ C_1 = 0; 4) 0 \leq C_2 \leq h_{m_1}; 5) 0 \leq C_3 \leq h_{m_1}; 6) C_4 = h_{m_2}; 7) 0 \leq C_5 \leq h_{m_2}. $$

Restriction on transporting ability of a stream

$$ C_4 L_{kp} - C_5 L_{ot} = 0, $$

where $L_v$ - Zone of concentration of a runoff (according to Figure 1); $L_o$ - Zone of the beginning of loss; $L_{ot}$ - Zone of adjournment of sediments; $L_{kp}$ - zone of critical loss; $C_i$ - factors, on physical sense corresponding average to the maximal depth of loss on a site; $n$ - number of the periods of alternation of zones of critical loss and adjournment of sediments. Depends on length of a slope, quantity and intensity of sediments, agricultural background and etc.; $L_s$ - length of a slope; $H$ - falling of a slope; $h_{m_1}$ - The maximal depth of loss in a zone to corresponding initial length of loss, a variable depending on a chemical compound of water, dynamics of a stream, characteristics of a spreading surface, etc.; $h_{m_2}$ - the maximal size of loss in a zone of critical loss, also a variable depending on dynamics of a stream, granulometric structure of soil, a chemical compound of water, etc.

The given system of the equations contains 3 unknowns.
persons defined empirical by \((n, h_{\text{m}}, h_{\text{n}})\). In particular, the number of the periods can be defined under the following formula:

\[
\begin{align*}
  n &= X_1X_2X_3X_4X_5; \\
  X_1 &= 10.04+7.52 \cdot 10^{-1} \text{LS}^{1.0}; \\
  X_2 &= 1.078I_{\text{max}}/(0.01166+I_{\text{max}}); \\
  X_3 &= 1.179-0.0019171 \text{m}^{1.3}; \\
  X_4 &= 0.8378+0.0004172I_{\text{max}}^{2}+222.9/I_{\text{max}}^{2}; \\
  X_5 &= 0.9771+0.00922af,
\end{align*}
\]

where \(I_{\text{max}}\) - the maximal gradients on a slope, \(\%\); 
\(I_{\text{min}}\) - the minimal gradients on a slope, \(\%\); 
\(T_{\text{nn}}\) - Tnn- version soil and ground (3- chernozem ordinary on loess, 5 - chernozem ordinary on marl 4- chernozem ordinary on sand, 6- marly); af - agricultural background (1 - fall-plowed field, (winter crops, for snowmelt), 4 - rangeland, long-term grasses).

Relative error of model \(E = 3.003 \%, \) absolute error of model \(E_1 = 0.117, \) coefficient of correlation \(r = 0.999, \) criterion of quality of model (criterion Gaus) \(s/s = 0.049.\)

In a slope the water-currents which have generated at snowmelts, it is possible to define the maximal depth \((h_{\text{max}}, m)\) of water on following empirical dependence:

\[
\begin{align*}
  h_{\text{max}} &= X_1X_2X_3X_4X_5X_6X_7; \\
  X_1 &= 0.04742Ls/(89.09+Ls); \\
  X_2 &= 1/(106.8-29.65pHn+2.071pHn^2); \\
  X_3 &= 1/(1,519-0.3286zo+0.0375zo^2); \\
  X_4 &= 1/(0.9581-0.008324NaN+0.0006553NaN^2); \\
  X_5 &= 1/(1.848-0.070681c+0.0009172c^2); \\
  X_6 &= 1/(1.603-0.03258lp+0.0003012lp^2); \\
  X_7 &= 1/0.04742Ls/(89.09+Ls);
\end{align*}
\]

where \(Ls\) – length of a slope from a watershed up to gauge line measurements, m; \(Lc\) - gradients on a slope, \(\%\); \(pHn\) – acidity superficial 0-3 sm of a layer of slope; 
\(zo\) – depth of thawing of soils; \(NaN\) – The maintenance of sodium in the top 0-3 sm a layer of soils, mg/100 g; \(lp\) – depth fract soils, sm; \(NO_n\) – The maintenance of nitrates in the top 0-3 sm a layer of soils, mg/100 g; \(Wn\) – Humidity of soils; \(\%\); \(XS\) – quantity of precipitation for the autumn-winter period (November-March), mm.

Relative error of model \(E = 22.0\%, \) absolute error of model \(E_1 = 0.001 m, \) coefficient of correlation \(r = 0.88, \) criterion of quality of model (criterion Gaus) \(s/s = 0.48.\)

As process of washout and accumulation is dynamical also places of the greatest washouts and adjournment vary depending on quantity of sediments, their intensity agricultural background, etc. it is necessary to spend a series of calculations for revealing zones of the most probable loss and adjournment of sediments. Besides at the long period of a runoff of a zone of loss tend to move progressively on a stream \([29]\), that also can be considered empirically at consecutive recalculations.

Place of accommodation of the first construction will be a point above the top border of the possible beginning of loss. The place of the beginning of loss can be calculated also by any existing technique \([32]\) on the basis of comparison of achievement by a stream of washing away speeds or tangents of pressure, etc. Dependences for definition of speeds of movement of water and tangents of pressure in slopping water-currents for different kinds of a runoff are presented in the appendix.

Distances between the subsequent constructions on a slope should be counted in view of change silt charge and the charge of water on length of a slope and in view of volume reservoir at a construction, and also admissible washout on a site. However, basically, if to start with preconditions of techniques existing on today for calculation of the subsequent distances between constructions it is possible to use the same formula, as for definition of a site of the first construction from a watershed, believing, that the top construction serves as a watershed for the remained part of a slope and calculation is conducted from a new watershed.

The offered method is more dynamical and considers прерывность process, unlike available. The binding to length of a slope allows to use it at creation of projects of land tenure with application GIS - technologies.

At application of agrotechnical ways of protection soils from erosion also it is necessary to have in view of, that the sequence of a combination agricultural background on slopes also can serve as the reason of strengthening of erosive activity of streams of water on a slope. Especially it concerns long-term grasses and rangeland. The soils under these agricultural background freezes through considerably, and thaws more slowly, than on others agricultural background, the significant roughness of a surface creates conditions for accumulation of a snow at which thawing energetically active streams of water not counterbalanced by sediments flow down on a surface of a slope and if below these agricultural background settle down agricultural background with smaller antierosion stability intensive loss of soils is observed.

### 4. Conclusions

The led researches allow to recommend to add existing system of designing of antierosion constructions on slopes in system of the organization of territory of land tenure with following positions:

1. Accommodation of the first construction and on a slope is necessary for projecting the subsequent above a place of concentration of a runoff, instead of on it as it is
done now. As in this place washout of soil and destruction of a construction is most probable.

2. Distances between constructions are necessary for appointing in view of a chemical compound of water as on short sites of a slope which are created at construction of constructions, the chemical component can appear more significant, than dynamic.

3. It is necessary to consider a crop rotation planned for given territories and system of fertilizers corresponding it since application of fertilizers promotes increase beaching substances, and will influence stability of constructions.

4. Alternation agricultural background on a slope should correspond to admissible change of hydrodynamical characteristics of water-currents so that transition from one agricultural background to another was not accompanied by strengthening of powerful activity of water-currents.

The system of crop rotations and system of fertilizers can be considered in calculations using a balance method of calculation the offered V.P.Gerasimenko and M.V.Kuman [13].

Advantages the soil- water-security organizations of territory of land tenure in adaptation of territories to changes of a climate consist in the following:

1) Long-term researches show maintenance of regulation maintenance with a moisture territories, creation of a favorable microclimate, preservation of fertility soils and a biodiversity vegetative and fauna;

2) At flooding the special organization of territory does not allow water to flow down quickly in downturn of a relief and it reduces peak of a high water, the that is stretches a freshet wave that reduces losses from a high water, the water distributed on a reservoir sates the top layer of soils and a zone of aeration, providing vegetation with a necessary moisture, and also preventing loss of a fertile layer of soils, in agrarian landscapes we promote productivity.

3) Growth of vegetation provides a favorable microclimate, shading a surface of the soil, reducing its warming up and heating of asphalt-concrete designs in settlements, favorably influences clearing of atmospheric air of dust and other polluting substances, etc.

The complex system of the organization of territory of land tenure will allow to reduce amplitude of fluctuations of heat and a moisture in problem territory and by that will lower probability of their flooding, loss, deficiency of water and desertification.

References


EDITORIAL

Recent Development in Hydro Science

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Hydro Science (HS) is a branch of science associated with engineering and technologies in hydraulics, hydrology, and water management. Its development is closely linked to the progress of human being civilization. Traditional HS has made a significant contribution to human living standard and health. The water treatment and supplying system and the city sewage system enabled people to have clean water to drink and have their wastewater removed. In addition, the irrigation hydraulic structures like channels and dams increased the product of agriculture to eliminate starvation in the world. In agriculture, understanding soil moisture and nutrient through hydraulic and hydrology research is crucial to develop strategies for product improvement [1].

The industrial revolution has transformed the sociology from traditional, agrarian into urban and industrial society. The role of HS expanded accordingly. The most significant change is the increase development of hydropower technologies. The kinetic energy of water, which has been used in the form of water wheels for centuries before BC, was utilised to generate hydropower in modern society. Hydropower as a type of clean energy has made significant contribution to mitigate climate change [2]. Research communities in maritime engineering are currently exploring the technology for harvesting energy from ocean waves, which would be a great contribution to the goal Net Zero greenhouse gas emissions target by 2050 [3].

The scope of HS also covers the science and engineering projects in ocean, especially on aquaculture, offshore oil and gas and offshore renewable energy. In terms of energy, the focus of offshore HS shifted from fossil fuel exploration and extraction to renewable energy (wind, tidal and waves) harvesting from ocean [4]. Consider that 70% of earth’s surface is covered by ocean, HS research on maritime will continuously play an important role in humankind evolution.

HS also involves the research on the protection of human lives and infrastructures from natural disasters, including floods, droughts, hurricanes, tsunamis etc [5]. Without advanced HS, it is impossible to establish accurate distracter warning systems, and design and construct effective infrastructures such as riverbanks, seawalls, breakwaters, irrigation systems, and so on, to withstand natural disasters. With the help of development of the

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communication system and computer power, HS reduces the loss caused by natural disaster significantly.

HS plays an important role in sustainable development globally. The United Nation’s 17 Sustainable Development Goals (SDGs) urge all countries to form a global partnership to tackle sustainable development issues. Among these issues, water, energy, oceans must be solved through HS and engineering.

Great number of scientists and engineers are working at the frontier of HS and Hydro Science & Marine Engineering provides an excellent platform for the publication of most updated research outcomes. The Journal focuses on innovative research methods at all stages and is committed to providing theoretical and practical experience for all those who are involved in HS.

References


