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ABOUT JOURNAL

Water is among the most precious gifts of the nature to mankind. Benign and life supporting in normal times, menacing during floods, and desperately sought in times of drought, the waters of the rivers, aquifers, springs, lakes, etc., have been part of our daily life. However, with the growing requirements of water for diverse purposes, water is becoming a critical and scarce natural resource and can not be regarded as available in abundance as might had been believed earlier. It is widely recognized that many countries are entering into era of severe water shortage. The increase is not only due to population growth but also due to improved life style of the people.

The dramatic expansion of urbanized areas, which has been witnessed over the last few decades is likely to continue in most countries of the world. Such, often unplanned, growth leading to the emergence of conurbation and mega cities, poses a threat to both the availability and quality of surface and groundwater resources. These threats are both unprecedented and of immense scale when viewed from political, social and economic perspectives.

The aim of the journal is to provide latest information in regard to developments taking place in the field of water resources, besides making aware the readers about the activities being carried out in the field of Water Resources, worldwide, such as technical papers, R&D Activities, and information regarding conferences, training programmes and important news.

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From the Editor's Desk

In response to the concern that the planet's freshwater resources are coming under increasingly pressure from competition amongst various users for a limited resource viz the recognition of ecosystem requirements, pollution and the risk of declining water availability due to climate change, the concept of Integrated Water Resources Management (IWRM) emerged around the 1980s.

IWRM addresses both the management of water as a resource, and the framework for provision of water services to all categories of users, and it addresses both water quantity and quality. In doing so, the basin (river, lake or groundwater) must be recognized as the basic unit for planning and management, and a firm societal commitment and proper public participation must be pursued. India has not yet reached the level of Water Resources Development as has been achieved by many developed countries. Therefore, there is a need in India to undertake developmental measures along with management measures. Central goal of IWRM at the river basin level is to achieve water security for all purposes, as well as manage risks while responding to, and mitigating disasters. The path towards water security requires trade-offs to maintain a proper balance between meeting various sectors' needs, and establishing adaptable governance mechanisms to cope with evolving environmental, economical and social circumstances. Well-developed, well-tested, scientifically robust, socially acceptable and economically viable approaches to implement IWRM at the river basin level are still not widely available. IWRM strives for effective and reliable delivery of water services by coordinating and balancing the various water-using sectors, which is an important part of sustainable water management.

During the past decade, water scarcity issue has emerged as an important theme in discussions on India's future. Global discourse suggests that India, and other developing countries in Asia and Africa, can respond to water scarcity and the resultant water poverty being faced by their people, by embracing integrated water resources management. A package of best practices for improved management of water resources with strong emphasis on direct demand-side management.

There is need for adopting a comprehensive and integrated approaches to address the problems which may inter-alia include adoption of efficient irrigation practices such as micro irrigation, selective lining, drainage development and suitable on-farm management, and conjunctive use of surface and ground water.

I am happy to inform that Indian Geographical Committee of IWRA and Central Board of Irrigation and Power are jointly organising a Seminar on Integrated Water Resources Management at New Delhi during 14-15 November 2019 with an objective to have discussions at National Level about the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystem. I request you and your colleagues & fellow professionals for active participation in the Seminar.

V.K. Kanjlia
Member Secretary
Indian Geographical Committee of IWRA

Physicochemical Analysis and Economic Evaluation of Lake Ecosystem - A Case Study of Lake System in Walajah Taluk, Vellore (India)

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ABSTRACT

Lakes are the most productive ecosystems, known globally for maintaining a wide array of biodiversity and also for providing various goods and services. But present increase in various anthropogenic activities such as intense agricultural practices and rapid urbanization have altered the physical, chemical and biological processes of the lake ecosystem, which has been proved by assessing a lake ecosystem in Walajah Taluk. The average economy generated by the two lakes combined was Rs.3041/sq.km/day. This study also revealed that the depreciation in the lake value is mainly because of the man-made activities, which may reduce its value in future. The minimum availability of lake water, because of improper rainfall and poor maintenance of lake, has led to the reduction in fish species and contaminations in the water. Even though the lake water meets the surface water standards in water quality analysis, it tends to get polluted during some human activities. This decline in the ecosystem values of goods and services along with the lake water quality signifies that there is a necessity in initiating environmental management strategies to recover its lost benefits.

Keywords *: Lake Ecosystem, Water quality analysis, Economic evaluation, Agricultural Expansion, Conservation techniques*

INTRODUCTION

Lake Ecosystem includes biotic plants, animals and microorganism, as well as abiotic physical and chemical interactions (Ramachandra et al., 2011). These ecosystems are prime example of lentic eco system and can be found in mountainous Ares, rift zones and areas with ongoing glaciation. They provide a lot of yields for human community, both directly and indirectly in terms of both eco system functions and bio diversity. An Eco system function refers to the habitat, physical and biological benefits of the ecosystem (Costanza et al., 1997). Various manmade activities which increases continuously, affect the eco system functioning, leads to the decline and degradation of the eco system services and also the economic value of the lakes. The most common issues encountered by the lakes are change in climatic conditions, loss of catchment area adjacent to urban growth, increasing runoff of nutrients and pollution, land clearance and over use of resources due to urbanization. The benefits that re lost during these changes are not valuated effectively in terms of both market values and economic services, (Reid et al., 2005) also neglected in policy decisions so the valuation of these eco system values must be done. It includes assigning a value in direct market for all the benefits of the lake eco system. Various use and non-use values associated with Lake Ecosystem are tabulated in Table 1.

Table 1 : Classification of Total economic Value for Lake (Jenkins et al., 2010)

Use values			Non-use values
Direct use values	**Indirect use values**	**Option value & benefits**	**Existence values**
Fish, Agriculture, Fuelwood, Fodder, Recreation Transport, Wildlife, Harvesting, Peat/ energy education	Nutrient Retention, Flood control, Strom protection, Ground water Recharge, External eco system, Support, Filtration, Micro-climate, Shoreline stabilization	Potential future use, Future value of information	Biodiversity, Culture, Heritage, Bequest

Economic evaluation is a valuation technique of assigning values for the products and services that are derive from the ecosystem, in terms of market price. These products are generally categorized in economic terms as use and nonuse values. The valuation technique used for assessing the lake ecosystem is contingent valuation technique, where the information are derived by interacting with the local people with help of questionnaires and the details regarding the amount they pay for procuring a good or value. It is a survey based method and the valuation is dependent on a hypothetical scenario put to respondents. This contingent evaluation technique is carried out in various steps by defining the goods and the scope of the goods, Conducting focus groups on components of the survey, pretesting the survey instruments (questionaries') and administering the questionnaires to the random samples.

Many economic valuation studies have been done all over the world, but mainly in developed countries. This study is also been carried out in India because of the expansion in the agricultural sector, hydrological alteration along with urbanization (Bin et al., 2005). This method has also helped in restoring the economic services of floodplain area in Mississippi alluvial valley. (Jenkins et al.,2010; Matthew et al.,1999). This method of study revealed the decrease in the water quality due to excessive discharge of sewage and industrial effluents in Hebbel lake (Ramachandra, 2008). It also revealed the cause of high fish mortality because of sudden fall of dissolved oxygen level in Sankey Lake. The proof for the fish mortality in Ulsoor Lake was justified using this study method (Anoop et al., 2007).

Walajah Taluk is one of the most prominent Taluk in Vellore district and is situated adjacent to Ranipet, one of the most industrialized places in Vellore. Since it is located next to this Ranipet, it also experiences a small effect in terms of environment and groundwater sources because of the leather tanneries. Also because of its rapid urbanization and expansion in agricultural activities the lake systems in this Taluk are at risk and also their values are decreased to a greater extent. This study has been done taken into account that the values of the lake eco system are affected because of the urbanization and hydrological alterations. The quality of the water was also analyzed and the various values from it have been assessed.

The primary objectives were to : (1) Analysis the physiochemical water quality variables and (2) Valuate the lake system economically using contingent valuation technique.

METHODOLOGY

Study Region

The study was done in Periya Lake (Lake 1) and Chinna Lake (Lake 2), two most prominent lakes situated at the east of the Vellore with the co-ordinates of 13° 01' N and 78° 75'E geographic position with a surface area of 3.6 sq km and 2.5 sq km respectively. These lakes provides water to 100 hectares of agricultural fields which grows crops like rice paddy, sugarcane, coconut, groundnut, brinjal and ladies finger. It also provides as water and fodder sources for various livestock grazing at its banks. These two lakes are present at 4 km away from the palar river at downstream. The location of the two lakes is graphically displayed in Figure 1.

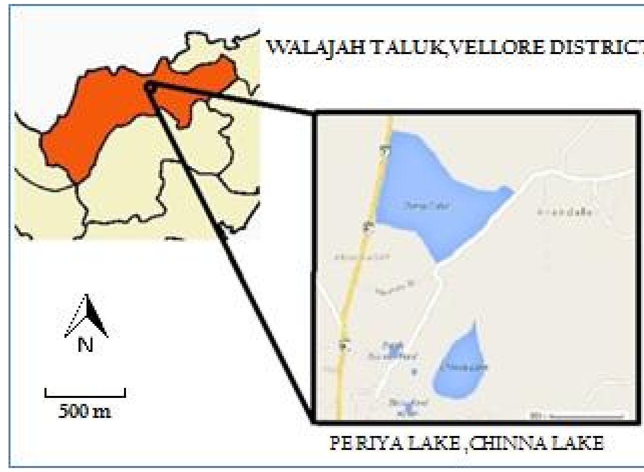

Fig. 1 : Map of Periya Lake and Chinna Lake in Walajah Taluk, Vellore

Water Quality Analysis

The water samples were collected at two different sites in both Periya Lake (Lake 1) and Chinna Lake (Lake 2) during month of October 2014 and were collected in polythene bottles and were preserved for analytical purposes. The physical variables like pH, Total Dissolved Solids (mg/L) and Electric Conductivity (μS/cm) was measured using battery powered electrometer, immediately after the samples were being collected. Other chemical parameters like hardness, chlorides, calcium, sodium, potassium, nitrates and phosphates were determined in the lab facility under standard norms.

Socio Economic Survey

The economic survey of the lakes based on contingent valuation technique, was done by interrogating 75 people randomly selected from the nearby villages with help of the questionnaires prepared for the survey purposes. The questionaries' were meant for collecting various information's including demographic information, domestic water usage, irrigational purposes, fishing purposes, water and fodder for livestock and groundwater availability. This was done in order to assess the economic status and reliability of the residents on the lake water. The demographic information includes the details of number of persons per houses, their occupation and annual income which is based on the dependency on the lake water for various purposes like irrigation, fishing and fodder for live stocks. Also the information regarding the availability of the groundwater resources was collected as it recharges local water bodies.

RESULTS AND DISCUSSIONS

Water Quality Analysis

The pH of all the samples ranged from 7.49-7.78. The total dissolved solids which play a major role in sedimentation ranged between 43.50-100.1 ppm. The electrical conductivity was found to be higher in Lake 2 199.6 µS-201.3 µS while the lake 1 had lower electrical conductivity 87.44 µS-87.89µS which was because of dissociation of soil at Lake 2. Dissolved oxygen was observed between 6.2-8 mg/L and the Chemical oxygen demand was found in the range of 96-160 mg/L, which was inside the permissible limit. The total hardness ranged from 160-200 ppm, while the alkalinity was found to be in between 60-110 mg/L, which indicates that both are inside the permissible limit. The nitrates were in the concentration of 0.2-0.3 mg/L whereas the phosphates varied from 1.22-2 ppm. The consolidated data of the physicochemical properties of various samples have been tabulated in Table 2.

Socio Economic Survey

For assessing the value for the goods and services and also determining dependency rate, 75 peoples from the nearby villages were surveyed. The list of resources and their economic values are tabulated in table

Domestic use : From the people surveyed, it was inferred that all were either using bore well water or well water, which comes under the category of indirect use value. This was because the bore wells and the wells were recharged by the influence of these lake systems. Here, a family with four individuals in an average utilizes 200 liters of water/day, which accounts up to Rs.21,900/house/year, while for drinking water they spend Rs.29,200/house/year.

Agriculture : The number of people indulged in the farming and agricultural activities were 45 out of 75 peoples. The main crops irrigated in the surrounding areas were rice paddy, sugarcane, groundnut, brinjal, ladies finger and coconut. The amount of water consumed from periya lake (Lake 1) was 150 liters/house/day while houses near chinna lake (Lake 2) consumed 220 liters/house/day which accounted to Rs.3,24,000 and Rs.4,75,000 respectively.

Livestock : Among the 75 people, nearly 25 people rear livestock with an average 4 animals/house, consisting of cows, goats. Various aquatic weeds growing around the lake were used as fodder for cattle. So the dependency of livestock fodder and washing the cattle's sum up to Rs.500/month and Rs.300/month.

Fisheries : 6 people who are living nearby the lakes involved in fishing, under tender basis. From the survey, it can be concluded that fishing acts as an important source for the lake Value. The total cost received from this was nearly Rs.7, 00,000/year.

Firewood (Energy) : The dependency for the fuel from waste wood accounts to Rs.7500/month.

The people who are nearby and surrounding villages, have been residing there for past 60-70 years. The lake water

Table 2 : Physicochemical properties of various lake water samples

Variables	Periya Lake Analysis (Lake 1)		Chinna Lake analysis (Lake 2)		Surface Water Standards (permissible limit)
	Site 1	Site 2	Site 3	Site 4	
pH	7.49	7.52	7.78	7.71	6.5 – 8.5
TDS (ppm)	43.5	46.3	100.1	103	<500 ppm
Electric Conductivity (µS)	87.89	89.4	199.6	197.8	<1200 µS
Total Alkalinity (ppm)	60	65	103	108	<600 ppm
Total Hardness (ppm)	160	165	200	202	<300 ppm
Calcium Hardness (ppm)	60	59.8	52	50.3	<80 ppm
Chemical Oxygen Demand (mg/L)	128	96	160	160	<200 mg/L
Nitrates (ppm)	0.3	0.32	0.2	0.25	<20 ppm
Phosphates (ppm)	2	1.89	2.2	2.22	<5 ppm
Chlorides (ppm)	90.75	113.44	81.67	77.13	<200 ppm
Dissolved Oxygen (mg/L)	6.4	6.6	7.6	8	>5 mg/L
Sodium (ppm)	100	110	106	110	<300 ppm
Potassium (ppm)	15	16	14	16	<20 ppm

served them as the primary water sources for drinking and irrigation, the plants and weeds in and around the lake as fodder for livestock. From the water quality analysis, it has been clearly verified that the water in both the lake systems were satisfying the surface water standards. Since, there was no addition of any industrial effluents or sewage discharge into the lake system, the water level was under the permissible limits. Table III depicts the list of resources and their respective economic values.

It was also noted during the time of survey and also at the time of evaluation, that the values derived from the Chinna Lake (Lake 2) were greater than that of Periya Lake (Lake 1). The reason for this difference is because of the poor maintenance condition of the lake and also the low availability of the water due to lack of inlet and outlet for storm water to flow into it. This leads to the depreciation of the former lake than compared to the latter one.

Table 3 : List of resources and their Economic Values

Use Values	Quantity of Resource	Lake value in Rupees.
Domestic Use	25-50 litres/ person/ day	31,97,984/ year
Agriculture (income)	150-220 liters/ house/ day	7,99,000/year
Fisheries	6 persons/year	7,00,000/year
Domestic Animals	4 animals/house	7500/year
Fodder for Domestic Animals	912 kg/year	54,75,000/ year
Fire wood	7500/month	9,18,000/year
Total		Rs. 1,10,97,484/ 10 sq.Km/year

Calculation: Rs.1,10,97,484/10 sq.km/year

= Rs.11,09,748.4/sq.km/year

= Rs.3,041/sq.km/day

Causes of Depreciation in Periya Lake (Lake 1) values

Since the availability of water to land is very less, this causes the people to mine the lake bed and sell it. Unfortunately, because of lack in lake bed soil, the water runs away without stagnating and also causes soil erosion.

Because of low availability of lake water during the time with low rainfall, the lake receives only a little amount of water when compared to its size. So, a majority of the land is available without water. These lands are acquitted for the sake of agricultural expansion, thus permanently making all to consider as a cultivation land. But during heavy rains, these lands also tend to get flooded with lake water, this results in fertilizers being carried away into the lake system. This increases the chemical concentration of lake when the level of water decreases during summer season.

Rapid growth in population and urbanization forces the people to make use of the dried up land along the lake banks, for building residential structures. This reduces the space for the water to get stagnated into lake and runs off with erosion.

Management of Lakes to Sustain Goods and Services

This study shows that there is a need of management in order to improve the use value of the ecosystem. The various methods and strategies that can be implemented are: (1) restoration of the lake ecosystem-procure the acquitted land and maintain it, (2) renewate and maintain the inlet and outlet system of the lakes, (3) periodically monitor and regulate the quality of water, so that the lake water always remain pollutant and contaminant free.

CONCLUSION

The water quality analysis explains that the water in both lakes are under the standard surface water norms, while it may get polluted if exposed to any man made activities in the lake area and their surroundings. But the socio-economic survey explains about the depreciation of the Periya Lake (Lake 1) values because of various activities like hydrological alteration, agricultural expansion and followed by urbanization -*by improving and maintaining the water quality many more species of fishes can be introduced into the lake ecosystem, which would help in the improvement of fishing values.in order to maintain and develop the resources that have been lost due to man-made activities must be regained back by periodically monitoring the quality of the water, prevent drastic land cover being converted into a catchment area and also creating the awareness among the people and implementing effective strategies to maintain the resources and values forever.

Acknowledgement

It's worth mentioning that my co-author Ms. Shalini Palani helped me a lot in performing all the water quality analysis throughout the project. I also, thank the environmental quality monitoring lab in charge and instructors at VIT University, for providing me the facility to do the analysis works. I would express my whole hearted thankfulness to the people who helped us in filling the questionnaires at the project area (Walajah Taluk, Vellore District).

REFERENCES

1. Ramachandra T V, B Alakananda, Ali Rani And M A Khan, Ecological and socio economic assessment of Varthur wetland, Bengaluru (India),Environ Science & Eng. Vol 53 No 1 p 101-108,January 2011.
2. Costanza R, d'Arge R, Rudolf de Groot, Farber S , Grasso M •The value of the world's ecosystem services and natural capital.Nature,387,25-260(1997)

3. Reid P, Millennium ecosystem assessment, Ecosystem and human well-being synthesis (island Press),Washington DC,2005
4. Jenkins,W A, Murray, B C, Kramer, R A And Faulkner S P, Valuing Ecosystem services values of wetlands restoration in Mississippi Alluvial Valley, Ecolog Econ, 691051-1061(2010)
5. Anoop P, Suryaprakash S, Umesh K B, Amjathbabu T S, Economic valuation of Use Benefits of Asthamudi Estuary in South India, Proceedings of Taal 2007:The 12th World Lake Conference:1822-1826
6. Matthew A. Wilson and Stephen R Carpenter, Economic valuation of fresh services in united states: 1971-1997, Ecological Applications, 9(3),1999, pp.772-783
7. Bin Z, Bo L,Yang Z, Nobukazu N and Jiia-Kuan, Estimation of Ecological Service Values of Wetlands in Shanghai, China, Chinese geographical Scince,15(2),151-156(2005)
8. Ramachandra T V, Spatial analysis and characterization of lentic Ecosystem: A case study of Varthur Lake, Bangalore, Int.J Ecol.Dev., 9(8), 39-56(2008)

Rainfall Runoff Estimation using SCS Model and ARCGIS for Micro Watershed in Cuddalore District

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ABSTRACT

Surface Runoff is one of the important parameter in hydrological studies. The estimation of surface runoff is necessary to design any hydraulic structure and also to determine flood risk analysis. The present study aims to calculate the surface runoff by using remote sensing and Arc Gis and the method used to calculate the runoff volume is SCS curve number method. The study chosen was Cuddalore micro watershed in Cuddalore district of Tamilnadu. The Total area of the taken for this study is 58.54 km². The soil map and land use and land cover maps were created in Arc gis software. The curve number values for the study area is calculated based on natural resource conservation service (NRCS) standard table. The estimated runoff in the study area is 4260 mm.

Keywords *: Run off, SCS-CN, ARC GIS, land use and Land cover, soil.*

INTRODUCTION

Rainfall means the drainage or flowing off precipitation from a catchment area through a surface channel (Handbook of Subramanya) A rainfall-runoff model is a mathematical model describing the rainfall-runoff relations of a catchment area, drainage basin or watershed. More precisely it produces the conversion of rainfall into runoff (Sundar Kumar et al 2013). The hydrological model was separated into three categories according to complexity and application, including lumped conceptual rainfall-runoff model, distributed hydrological model and global hydrological. (Hongxia et al, 2015). The SCS method is widely used in the design of major hydraulic structures such as culverts, detention basins, stream relocation and large drainage ditches (AnubhaTopno et al. 2015). The need for accurate information on watershed runoff and sediment yield has grown rapidly during the past decades because of the acceleration of watershed management programs for conservation, development and beneficial use of all natural resources including soil and water (Mishra et al. 2103)Mishra and Singh model which is based on soil conservation curve number (SCS-CN) methodology but incorporates the antecedent moisture in direct surface runoff computations. They used this method in five sub basins and proved that the performance of the MS model is better than the original SCS-CN method. Bal gopal guru (2015). A comparative analysis of ArcCN-Runoff and ArcSWAT reveals that ArcCN Runoff model gives 90% of rainfall in the form of runoff and 75% of rain fall becomes surface runoff from arc SWATmodel.The result obtained using digital hydrological model can be very much used for runoff estimation with more accuracy and very short processing time (Narasayya.Kamuju 2015). Estimation of direct rainfall-runoff is always efficient but is not possible for most of the location at desired time. Use of remote sensing and GIS technology can be used to overcome the problem of conventional method for estimating runoff caused due to rainfall (Ratika Pradhan et al. 2010) Surface runoff and sediment losses are the two important hydrologic responses from the rainfall events occurring over the watershed system (Gajbhiye et al 2014). Application of mathematical modeling techniques to the constituent processes involved in the physical processes of runoff generation has led to better understanding of the processes and their interaction (Venkata Ramana 2014). Many models were developed for watershed hydrology but the availability of temporal and spatial data was the main constraint hindering the implementation of these models especially in developing countries (Saubhadip Kangsabanik et al 2017). Nevertheless, a number of studies which consider recorded rainfall-runoff events from gauged catchments, is still very limited (Banasik et al 2010).The NRCS-CN method has gained general acceptance in engineering practice due to its simplicity in estimating storm water runoff depth from rainfall depth (DAsaro 2012).There are two types of concepts which are responsible for runoff generation. These are the infiltration-excess runoff and the saturation excess runoff. (Ankit Balvanshi et al 2014). The runoff values estimated by the curve number technique, it is possible to assess which month has more runoff, which month has a moderate runoff low runoff month. With the help of these values, Irrigation scheduling, rotation of cropping pattern and selection of suitable crops can be suggested (Nagarajan et al. 2113). The analysis carried out using

IRSID LISS III satellite images in the form of FCC using SCS curve number method and found that the result is reasonably good (Somashekar 2011). Even calibrated curve numbers contain large uncertainties, thus requiring statistical proof that estimated runoff adequately agrees with observations (Tandon 2014). HMS-ASUFA is a very suitable to real time applications on both the small and large scales. In addition it is a feasible and efficient tool for hydrologists seeking accurate and quick morphological parameters calculation (Ashraf 2014).

STUDY AREA

Cuddalore micro watershed is located at Cuddalore district. It is the coastal zone of Cuddalore district and the main river in the study area is Lower Penniyar. The latitude and longitude of the study area are 11.74 and 79.76. Cuddalore district is bounded on the north by the Villupuram district and the Union territory of Puducherry, on the south by Nagapattinum, Thanjavur and Thiruvarur districts, on the west by Perambalur district and on the east by the Bay of Bengal. The district is located 160 km from south of Chennai the capital of Tamilnadu. The average annual precipitation is 1110 mm.

DATA USED

In this study variety of data including Toposheet from Survey of India, Rainfall data from Institute of water studies Tharamani, Chennai, Soil map prepared by National Bureau of soil survey on 1:250000 scale and land use and land cover image of the year 2011-2012 was downloaded from Bhuvan website, Indian geo platform of ISRO (www.bhuvan.nrsc.in) was used to prepare a land use and land cover map of the study area. (Figure 1)

MATERIAL AND METHODS

Land Use and Land Cover

The land use map downloaded from Bhuvan website was used to prepare a land use pattern of the study area. The original land use types were grouped into four groups as Agricultural, Forest, Urban and Water bodies.

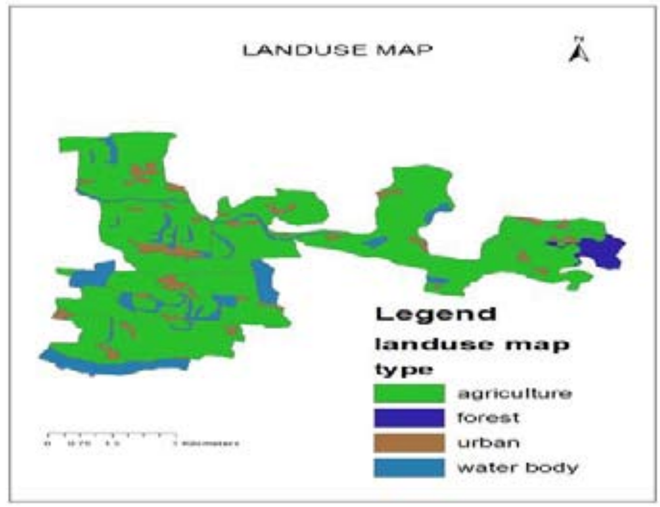

Fig. 2 : Land use and land cover map

SOIL MAP

The soil map of the study area is extracted by fixing watershed boundary in the soil map collected from National Bureau of soil survey and the soil groups present in the study area are Alfisols,Inceptisols and vertisols. (Figure 3)

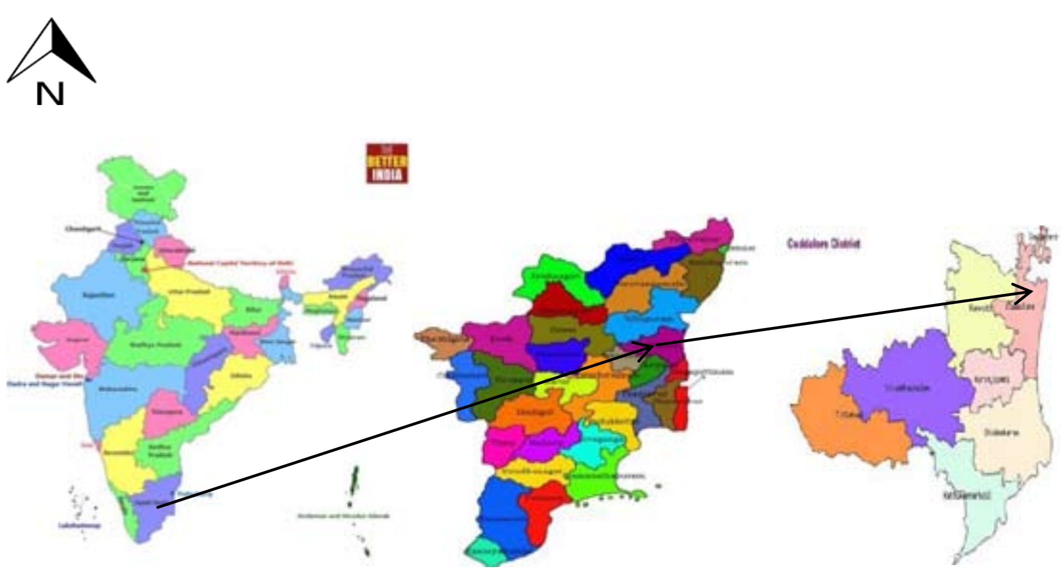

Fig. 1 : Study area Map

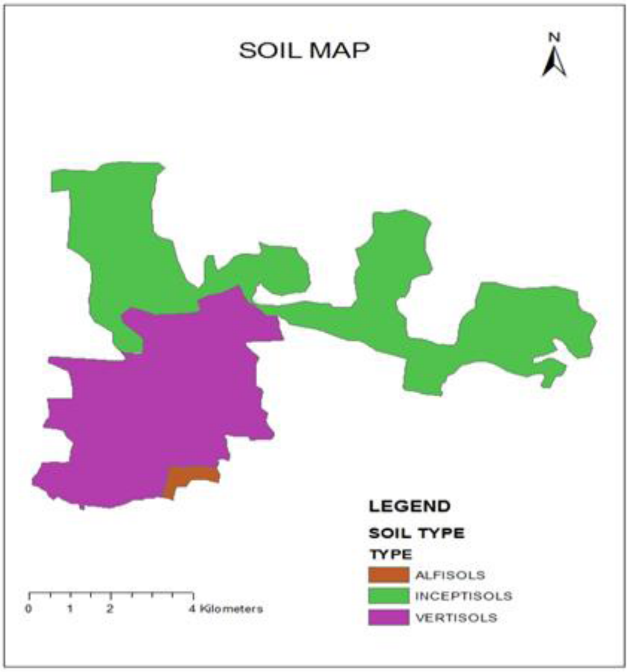

Fig. 3 : Soli Map

SCS Method

The SCS-CN method is developed in 1954 by the USDA soil conservation service. This method is based on water balance equation and two functional hypotheses. The first hypotheses is that ratio of the actual amount of direct runoff to the maximum potential runoff is equal to the ratio of the amount of actual infiltration to the amount of the potential maximum retention. The second hypotheses is that the amount of initial abstraction is some fraction of the potential maximum retention (Subramanya).Water balance equation is

$$P = I_a + F + Q \qquad ...(1)$$

Where,

P = total precipitation, IA= Initial abstraction, F= Cumulative infiltration , Q = direct runoff

From first hypotheses,

$$\frac{Q}{P - I_a} = \frac{F}{S} \qquad ...(2)$$

From second hypotheses,

$$I_a = \lambda S \quad ...(3)$$

Combining equations 2 and 3

$$Q = \frac{(P - I_a)}{P - I_a + S} = \frac{(P - \lambda S)^2}{P + (1-\lambda)S} \quad \text{for} \quad P > \lambda S$$

$$Q = 0 \text{ for } P \le \lambda S$$

For Indian soil condition the above relation is modified as

$$Q = \frac{(P - 0.3S)^2}{P + 0.7S} \lambda = .3 \qquad ...(4)$$

Curve Number

1. The curve number gives is bases on Antecedent moisture condition, soil group and land use and land cover pattern of the study area For convenience in practical application the soil conservation service (SCS) of USA has expressed S (in mm) in terms of a dimensionless parameter CN (the curve number) as

   CN = (25400)/S- 254)

And has a range of 100≥CN≥0.

Antecedent Moisture Condition (AMC)

It refers to the moisture content present in the soil at the beginning of the rainfall-runoff event under consideration. It is well known that initial abstraction and infiltration are governed by AMC. For purpose of practical application three levels of AMC are recognized AMC are recognized by SCS as follows

1. AMC-I: soil are dry but not to wilting point. Satisfactory cultivation has taken place
2. AMC-II: Average condition
3. AMC-III: Sufficient rainfall has occurred within the immediate past 5 days. Saturated soil condition prevail

Table 1 : Antecedent moisture condition (AMC) for determination the value of CN

AMC type	Dormant Season	Growing Season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

Soil Group

Group-A : Deep sand, Deep loess, Aggregated silt.

Group-B : Shallow loess, Sandy loam, Red loamy soil, Red sandy loam, Red sandy soil.

Group-C : Clayey loam, Shallow sandy loam.

Group-D : Heavy plastic clays, Certain saline soils.

RESULTS AND DISCUSSIONS

The land use classification of Cuddalore water shed is given in Table 1 shows that 81.14 % of land is used for agriculture, 10.92 % land is water bodies, 3.37 % land

Table 2 : Runoff curve number [CNII] for hydrology soil cover complexes

Land use	Cover		Hydrological soil groups			
	Treatment or practice	Hydrologic condition	A	B	C	D
Cultivated	Straight row		76	86	90	93
Cultivated	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
Cultivated	Contoured & Terraced	Poor	66	74	80	82
		Good	62	71	77	81
Cultivated	Bunded	Poor	67	75	81	83
		Good	59	69	76	79
Cultivated	Paddy		95	95	95	95
Orchards	With understory covers		39	53	67	71
	Without understory covers		41	55	69	73
Forest	Dense		26	40	58	61
	Open		28	44	60	64
	Scrub		33	47	64	67
Pasture	Poor		68	79	86	89
	Fair		49	69	79	84
	Good		39	61	74	80
Wasteland			71	80	85	88
Roads (dirt)			73	83	88	90
Head surface area			77	86	91	93

was urban and 1.27% land was forest area.The soil group of the soil in the study area is group B. Table 4 gives three different CN values based on Antecedent moisture condition. The calculated runoff depth for the study area is 4260 mm.

CONCLUSION

SCS-CN model is the simplest model to calculate the runoff for a study area. This SCS model along with GIS will give a more accurate runoff value for ungagged streams and rivers. Remote sensing and GIS are used to identify and create a map for land use and soil type. In the present study remote sensing and GIS were used to calculate CN value which can used to estimate runoff depth for larger area with lesser time period.

Table 3 : Land use /land cover classification

S. No	Type	Area (sq.km)	Area in percent
1	Urban	3.37	5.77
2	Forest	1.27	2.17
3	Water	6.4	10.92
4	Agriculture	47.5	81.14

Table 4 : Curve Number

Sl. No.	AMC	CN	S
1	AMC - I	68.05	119.25
2	AMC - II	82.93	52.28
3	AMC - III	91.92	22.32

REFERENCES

1. Agnese, C. Grillone, G. and Asaro, F.“Comparison of temperature data collected in urban and agricultural areas surrounding” Italian Journal of Agrometeorology, 13 (1), 48- 49. 168
2. Binguuo, W. Obeysekera, J. and Shih, G. “Spatial analysis for monthly rainfall in South Florida” Journal of American Water Resources Association, 29(2), 179-188.
3. Chiew, A. A. M. Baki, A. M. and Atan, I. “Synthetic Simulation of Stochastic Rainfall Runoff Model” UMTAS 2011, 140-146.
4. David Lorenz. King, J. P. and Bawazir, A. S. “Forecasting monthly streamflow of springsummer runoff season in Rio Grande headwaters basin using

stochastic hybrid modeling approach" Journal of Hydrologic Engineering, 16(4), 384–390.

5. DeVrieset. and Rat, A. "Evaluation of neural network streamflow forecasting on 47 watersheds" Journal of Hydrologic Engineering, 10(1), 85–88.
6. Grove. "Analyzing curve number model in estimating flood by using geographical information systems" MA dissertation, The Faculty of Natural Resources and Maritime Sciences, Tarbiat-e-Modarres University.
7. Hjelmfelt, S. M. Jarsjö, J. and Destouni, G. "Vapor flux by evapotranspiration: Effects of changes in climate, land use, and water use" Journal of Geophysical Research,115,1-8.
8. Hjelmfelt, S.M. and Dutta, D. "Analysis of water resources in the Mahanadi River Basin, India under projected climate conditions" Hydrological Processes. 22, 3589–3603.
9. Hosking, S. M. "Hydro-climatic change in irrigated world regions" Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden. 169 Babul, S.K. Khadar, Karthikeyan, K. Ramanaiah, M. V.
10. Lee. andKarapataki, C. "Comparison of multivariate regression and artificial neural networks for peak urban water-demand forecasting: Evaluation of different ANN learning algorithms" Journal of Hydrologic Engineering, 15(10), 729–743.
11. Mishrae, Hirotugu. "A New Look at the Statistical Model Identification" IEE Transactions on Automatic Control, 19 (6), 716–723.
12. Mooreet. "Prediction Of Rain-Fall Flow Time Series Using Auto-Regressive Models" Advances In Applied Science Research, 2 (2), 128-133.
13. Osterkampet. andLauzon, N. "Generalisation for neural networks through data sampling and training procedures, with applications to streamflow predictions" Hydrology and Earth System Sciences, 8(5), 940–958.
14. Rasoulzadeh. Cui, C. King, J. P. Abudukadeer, K. "Comparison of performance of statistical models in forecasting monthly streamflow of Kizil River, China" Water Science and Engineering, 3(3), 269-281.
15. Segun. King, J.P. and Pagano, T.C. "Application of Partial Least-Squares Regression in Seasonal Streamflow Forecasting", Journal of Hydrologic Engineering, 15(8), 612-623.
16. Sturm, R. J. and See, L. "Comparing neural network and autoregressive moving average techniques for the provision of continuous river flow forecasts in two contrasting catchments" Hydrological Processes, 14(11-12), 2157-2172.
17. Talbot, V. Perrain, C. Michel, C. Usart-Sanchez, I. and Lavabre, J. "Impact of imperfect rainfall knowledge on efficiency and the parameters of watershed models" Journal of Hydrology, 250, 206–223.
18. Yu, M.K. Corzo, G.A. Andel, S.J.V. and Jonoski, A. "River flow forecasting with Artificial Neural Networks using satellite observed precipitation pre-processed with flow length and travel time information: case study of the Ganges river basin" Hydrology and Earth System Sciences Discussion, 6, 3385–3416.
19. Engineering Hydrology Handbook of Subramanya K
20. Kavisri M (2015) Modeling of flow in an unsaturated zone of tank clustered catchment using Geo-spatial technology.pp 14529-14536.

Optimal Operation Study of Reservoir System Using Optimization and Simulation Techniques - A Case Study of Uduthorehalla Reservoir in India

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ABSTRACT

The number of uncertainties involved in the water reservoir system makes it difficult to apply any one particular technique to study it completely. Hence, a study of Uduthorehalla Reservoir in Karnataka, India is done in this context using an optimization and simulation techniques. In this paper, an optimization model is formulated and applied to the Uduthorehalla Reservoir. The annual firm yield is computed using Linear Programming and simulation techniques for 100%, 75% and 50% reliabilities. The firm yields obtained by using continuous yield model, approximate yield model and simulation techniques are 22.73 MCM, 22.67 MCM and 21.89 MCM respectively for 100% reliability level. The monthly targets achieved are close to the respective demands.

Keywords : Uduthorehalla Reservoir, Linear Programming, Simulation, LINDO, yield model.

INTRODUCTION

The ancient colonies of mankind were established near water bodies. It highlights the importance of water to him. The history witnesses wars over the sharing problems of water. For getting the beneficial use of water, people constructed a number of hydraulic structures over rivers,streams and other water bodies. A large number of small and large dams have been constructed. The dam construction is a very expensive and huge structure. Hence, its proper construction and the management of the stored water on its upstream make a water reservoir project sustainable and economical. In view of the scarcity of water, the dam reservoir operation needs a judicious and scientific approach. An efficient regulation of reservoir leads to an increase in benefits from the reservoir. The reservoir operating rules have been extensively studied over last some decades. The policy of storing and releasing the water from reservoir needs a careful study of the associated hydrological parameters. The water resources planning and management involves the supplies in accordance with the temporal and spatial distribution of the demand keeping in view the water availability.

Linear Programming (LP) has been the most popular optimization tool in water resources engineering especially in reservoir operation studies. It can handle large number of variables and constraints. The computer software packages like LINDO, LINGO, CPLEX, MINOS etc. are easily available. The LP converges to a global optimal solution quickly. The more refinement to the optimal solution obtained by LP can be given by the simulation technique, which is more realistic and nonlinear in nature. Hence, in the present study, these two techniques are successfully applied to study the system analysis of the Uduthorehalla Reservoir Project.

For the preliminary analyses of alternative plans prior to more detailed stochastic optimization or simulation study, deterministic models using selected values of uncertain inputs, parameters, and variables can be useful (Sharma, 2011). The deterministic model assumes that the unregulated stream flows at any site in the basin in any time period equals the historical average or some critical value for that site and period. This assumption ignores the natural variability of such flows and the need to consider over-year as well as within-year active reservoir storage capacity requirements. A detailed study about yield models was done and applied to a system of eight reservoirs in the upper basin of the Narmada River in India (Dahe et al.2002). The basic yield model was extended and presented a multiple-yield model for a multiple-reservoir system consisting of single-purpose and multipurpose reservoirs. The objective was to achieve prespecified reliabilities for irrigation and energy generation and to incorporate an allowable deficit in the annual irrigation target. The Integrated Reservoir Yield Model (IRYM) was applied to a multiple reservoirs system consisting of two major and four medium reservoirs of Maner sub-basin of the Godavari river basin (Shreshtha, 2009). The model was proposed to estimate the optimal annual multi yields of predefined reliabilities and the optimal crop plan. The results were very close to that proposed by National Water Development Agency (NWDA), India. A comprehensive study was carried out for deterministic distribution of future water storage shortages based on known existing demands and the historical data (Sharma et al.2011). The study aimed at maximizing the annual safe reservoir yield. Conjunctive use of surface and ground water was studied which offers a great potential for enhanced and assured water supplies at minimum cost (Chowdhary et al.2012). The study was aimed at developing a linear programming model to determine a stable conjunctive use policy for irrigation in a reservoir –aquifer system for multiple crops in a reservoir canal command area for a normal year. An LP-based yield model (YM) has been used to re-evaluate the annual yield available from the reservoirs for irrigation (Pattewar, 2013).The study involves extension of the basic yield model and presents a yield model for a multiple-reservoir system consisting of single-purpose reservoirs

DESCRIPTION OF THE STUDY AREA

Uduthorehalla Project is a Medium Irrigation Project (Location: Longitude 77˚ 19’58” E and Latitude 11˚55’58”N) constructed across river Uduthorehalla in Chamarajanagar district of Karnataka, India. It is located in Cauvery Basin in Karnataka. The Uduthorehalla Reservoir project has a gross storage capacity of 21.2 MCM with live storage of 16.24 MCM. The Dead storage capacity is kept at 4.96 MCM. The estimated 50% dependable yield at dam site is 37.27 MCM, and 75% dependable yield is 28.89 MCM. The Gross commanded area under the scheme is 8,597 Ha and the cultivable command area proposed for fresh irrigation is 6,272.5 Ha. The catchment area is 202.2 sq.km. The monthly inflow data of 26 years (1950-51 to 1975-76) is considered for study (Subodh Kumar et al., 2008). (Fig. 1)

From the monthly inflow data of 26 years (1950-51 to 1975-76), an annual inflow of 14.55 MCM is the lowest inflow on record in the year 1952, while in the year 1972, the maximum inflow of 59.95 MCM is observed. The average annual inflow for the specified period is 37.37 MCM. In the month of October an average monthly inflow is 8.6 MCM which is the maximum, while in the month of April, it is as low as 0.2 MCM. (Table 1)

Fig. 1 : Index map of Uduthorehalla Project, Karnataka, India

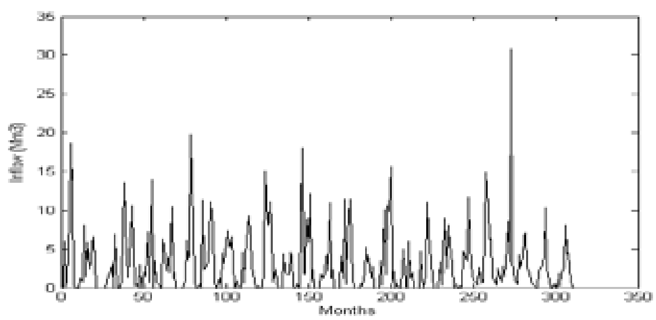

Fig. 2 : River inflow (for period 1950-51 to 1975-76)

METHODOLOGY

Generally, the lowest recorded natural flow of the river for a number of years is taken as the critical dry period for determining the safe yield. The uniform rate at which water can be drawn from the reservoir throughout a dry period is often referred to as the “firm yield” or “safe yield”. The number of years of reservoir yield failure determines the estimated reliability of each reservoir yield. An annual reservoir yield that fails in *f* years has an estimated probability [(*n*-*f*) / (*n*+*1*)] of being equaled or exceeded in any future year. If no reservoir is built to increase the yields downstream of the reservoir site, the historic firm yield is the lowest flow on record. Associated with any historic yield is a probability that yield can be provided in any future year by a given size reservoir with a particular operation policy.

Table 1 : For the proposed project, the evaporation parameters (γ_t) are :

Months	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
γ_t	0.097	0.083	0.083	0.083	0.069	0.056	0.056	0.056	0.056	0.098	0.125	0.138

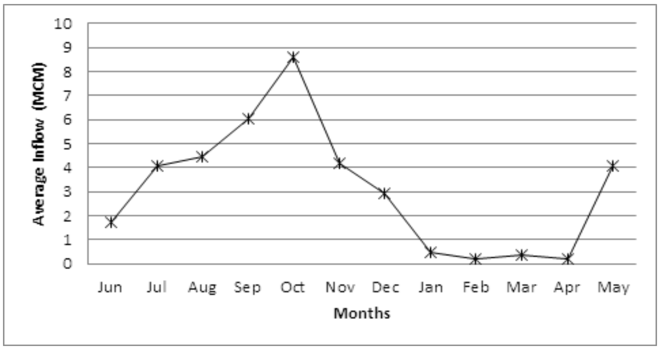

Fig. 3 : Average monthly inflow (for period 1950-51 to 1975-76)

(A) Formulation of the Continuous Model (Full Optimization Model)

The continuous model is a bulky model and consists of 26 years historical data for the period of 1950-51 to 1975-76. Monthly time step has been chosen to develop and run the model. Therefore, the size of the model becomes large enough. In the present study, an objective function to maximize the yield (Y) is used.

i.e. Maximize Y

Constraints are

(1) Storage continuity (mass – balance constraint) equation:

The relationship between the initial storage of a month and the final storage of that month is given by storage continuity equation. It is given by

$$S_{j,t-1} + I_{j,t} - Kt^{*}Y - Sp_{j,t} - Et = S_{j,t}$$

$\forall$ j, t, j =1…26, t=1…12 ...(1)

Where, $S_{j,\,t-1}$= initial storage in the month't' in year 'j'; $S_{j,\,t}$ = final storage in the month 't' in year 'j' (or initial storage in the month 't+1') ; $I_{j,t}$= inflow during the month't' in year 'j'; Et = Evaporation loss from the reservoir during time period 't' in year 'j'; $Sp_{j,t}$= Surplus from the reservoir during month't' in year 'j'; Kt = Predetermined fraction of annual yield for the within year yield in period 't'

(2) Reservoir Storage Capacity Constraints:

The storage in a month should be less than the active storage volume capacity. Also, it should not be less than the dead storage capacity. The relationship is given by

$$S_{min} \le S_{j,t} \le S_{max} \quad \forall\, j,t \qquad ...(2)$$

Where, S_{min}= Minimum Storage capacity of the reservoir in Mm^3;S_{max}= Maximum Storage capacity of the reservoir in Mm^3.

(3) Overflow constraint:

The overflow situation is handled by this constraint. When the final storage exceeds the reservoir capacity, excess amount is spilled over.

$$Sp_{j,\,t-1} = S_{j,\,t} - S_{max} \qquad ...(3)$$

and $Sp_j \ge 0$ ...(4)

(4) Evaporation loss constraints:

Evaporation loss in a month is computed by the evaporation rate in that month times the water spread area. It is calculated by assuming the linear relationship between the water surface area and the reservoir storage content above the dead storage level.

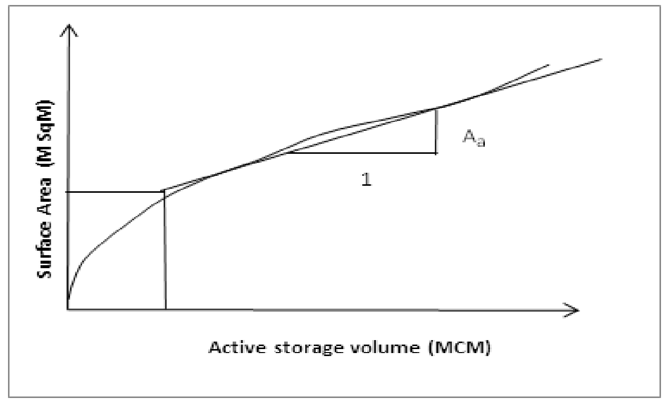

Fig. 4 : Surface Area versus storage volume

(B) Formulation of the Approximate Optimization Model

It is an approximation to the full optimization model. The size of the model reduces considerably. In this, the number of constraint equations is reduced from 2nT to 2(n+T), where n is the number of years of hydrologic record and T is the periods. The objective of the study is to maximize the over-year yield.

i.e. Max Y

Constraints are

(1) Over year storage continuity

$$S^{o}_{j-1} + I - \theta_{p,j}Y - Sp_j - El_j = S^{o}_{j} \quad \forall\, j \qquad ...(5)$$

Where, S^{o}_{j-1} = Initial storage at the beginning of year j; S^{o}_{j} = Final storage at the end of year j; Sp_j= Excess release in year j;El_j=Annual evaporation volume loss in each year j;

$\theta_{p,j}$= Failure fraction

=1, for successful year

=0, for completely failure year

(2) Over year active storage volume capacity

$$S^{o}_{j-1} \le K \quad \forall\, j \qquad ...(6)$$

Where, K = Over year active reservoir capacity

(3) Within year storage continuity

$S^w_{t-1}+\beta_t (Y+\Sigma_t EI_t)- Wy_t- EI_t = S^w_t \qquad \forall t$ ...(7)

Where, S^w_{t-1}, S^w_t = The storages at the start of months *t-1* and *t* respectively; β_t = Relative proportion of the critical year's inflow that is likely to occur in period *t*; EI^t = Within-year evaporation loss in each period *t* of the critical year

(4) Definition of estimated evaporation

$EI_j = E0 + [S^o_{j-1} + \gamma_t^* \Sigma_t (S^w_{t-1} + S^w_t)/2] EI^r$ ...(8)

Where, E0 = Average annual fixed evaporation volume loss due to dead storage; EI^r= Average annual volume loss rate per unit of active storage volume

(5) Definition of estimated evaporation losses

$EI^t = \gamma_t E0+ [S^o_{cr} + (S^w_{t-1} + S^w_t)/2]^* \gamma_t^* EI^r$ ...(9)

Where, γ_t = Fraction of the annual evaporation volume loss from reservoir in period

S^o_{cr} = Initial over year storage in the critical year

(6) Total reservoir capacity

$K+S^w_{t-1} \leq K_a \qquad \forall t$ ...(10)

Where, K_a = Total active storage capacity of the reservoir

(7) Proportioning of yield in within year periods

$Wy_t = K_t Y$ ...(11)

Where, K_t = Predefined fraction of annual reservoir yield for the within-year yield in period *t*

The above two models are solved using Linear Programming solver LINDO6.1 (**L**inear, **IN**teractive, and **D**iscrete **O**ptimizer).

(C) Simulation

It is the technique in which the actual system is represented by a model and the system performance under a given set of conditions is predicted. The model uses the continuity equation for a given period-

(Initial storage) + (Inflow) – (Evaporation loss) – (Release) – (Spill) = (Final storage)

The model is run for various sets of conditions which is a time consuming process. However, in the best combination of an optimization technique, the number of trials is reduced in simulation.

ANALYSIS AND RESULTS

For the study area, 26 years historic inflow data were studied to determine firm yield for various reliabilities. The failure years are considered to be complete failure years with no allowable deficit considered. The failure years are selected from among those in which permitting a failure increases the reservoir yield for the given reservoir capacity. The average annual fixed evaporation loss due to dead storage (E0) is obtained by the product of area at dead storage level and average annual depth of evaporation. Average annual volume loss rate per unit of active storage volume (EI^r) is the product of area per unit active storage volume above dead storage level and average annual depth of evaporation.

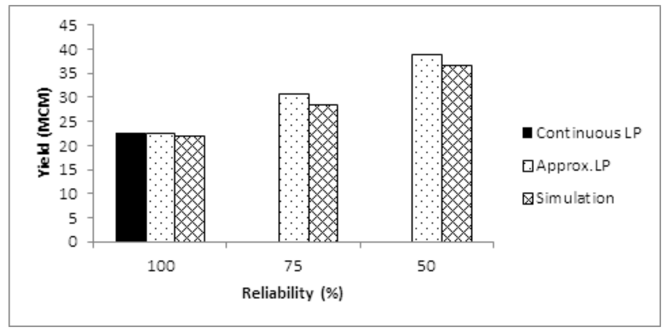

Fig. 5 : Comparative yields by various approaches

The complete and approximate yield models were developed and run for reliabilities of 100%, 75% and 50%. The simulation model was developed and run in C++ computer programming language. The 100% reliable yields of 22.73 MCM, 22.67 MCM and 21.89 MCM were obtained using continuous model, approximate yield model and simulation model respectively. The 75% yields obtained were 30.79 MCM and 28.63 MCM by using approximate yield model and simulation model respectively. The approximate yield model and simulation models resulted in 38.97 MCM and 36.57 MCM respectively for 50% reliabilities. The accuracy of the approximate yield model solution depends on the selection of β_t values which in turn are based on the critical year of the record.

The reservoir releases are obtained for various reliability levels (Fig. 7). It is also observed that the within-year yields are close to the demand pattern (Fig. 8) indicating the proper reservoir management.

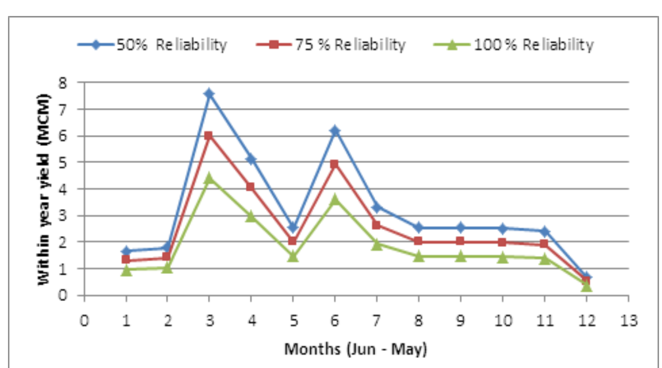

Fig. 6 : Within year yields for various reliabilities

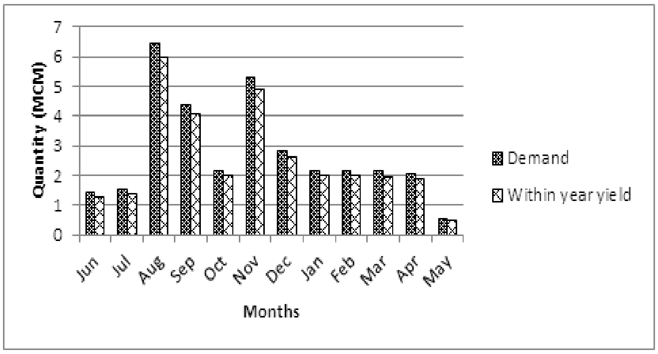

Fig. 7 : Comparison between demand and yield

CONCLUSION

The continuous yield model, approximate yield model and simulation models are successfully developed and applied for the Uduthorehalla Reservoir Project, Karnataka, India. The objective of the study was to maximize the firm yield of the system under consideration. The yield model for 75% reliability applied for the study area gives fairly good results satisfying the over year storage continuity, within year storage continuity, the reservoir capacity constraints. The within year yield values are found to be closer to the monthly demands.

(1) The accuracy of the approximate yield model solution depends on the selection of β_t values which in turn are based on the critical year of the record.

(2) In full optimization model monthly time step was considered for evaluation while in approximate yield model the time step considered was annual except for the predefined critical year, in which monthly time step was considered.

(3) The system was very well described by simulation model which gave fairly accurate results.

(4) The consideration of linear and nonlinear relationship between reservoir surface area and the reservoir storage volume affects the evaporation volume loss calculation and subsequently the system performance. For evaporation loss calculation, LP models use linear relationship while the simulation uses the nonlinear relationship between them. Therefore, more accurate results are obtained by using simulation approach.

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

REFERENCES

1. Chowdhary Archana, Srivastava R K. Operating Policies for Conjunctive Use planning for a Multipurpose Project, Journal of Indian Water Works Association, July-September (2012),173-183.
2. Dahe P D, Srivastava D K. Multireservoir Multiyield Model with Allowable Deficit in Annual Yield, ASCE, Journal of Water Resources Planning and Management, 128(6) November 1, (2002) 406-414.
3. Kangrang Anongrit, Anujit Phumphan,Witsanukorn Chaiyapoom. Stochastic Inflow Simulation for Searching Rule Curves, American Journal of Applied Sciences 5(3) (2008), 221-226
4. Pattewar Deepak V, Sharma Kalpeshkumar M, Dahe P.D. Yield Estimation for a Single Purpose Multi-Reservoir System Using LP Based Yield Model. Journal of Water Resource and Protection, 5(2013) 28-34.
5. Raju K S, Nagesh Kumar D. Optimum Cropping Pattern for Sri Ram Sagar Project: A Linear Programming Approach, Journal of Applied Hydrology, Vol.XIII,1&2,57-67.
6. Sharma Kalpeshkumar M., Pattewar Deepak V., Dahe P.D. Assessment of Safe Reservoir Yield by Full Optimization Model by Linear Programming Method, International Journal of Water Resources and Environmental Engineering (10), 21 October (2011) 204-211.
7. Shrestha K K, Jhajharia D, Srivastava D K.Systems Analysis of Reservoirs in Maner Sub Basin of the Godavari River Basin, Journal of Indian Water Resources Society,29(4) October(2009) 30-37.
8. Sinha Amit K, B. Vasudeva Rao, UpmanuLall.Yield Model for Screening Multipurpose Reservoir Systems, ASCE, Journal of Water Resources Planning and Management,125(6) November/December (1999) 325-332.
9. Subodh Kumar Panigrahi, Sanat Dash. Reservoir Operation Using Multiple Regressed Operation Rule, B.Tech Project,Department of Civil Engineering, National Institute Technology Rourkela, Rourkela, India.(2008),
10. Yeh, W.W.G. Reservoir management and operation models: a state of the art review, Water Resour. Res., 21 (1)(1985) 1797-1818.
11. Zahraie B., Hosseini S M. Development of Reservoir Operation Policies Using Integrated Optimization-Simulation Approach, Journal of Agr. Sci. Tech. 12 (2010) 433-446.

Sedimentation and Flushing Operation of Pandoh Reservoir

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ABSTRACT

Reservoir sedimentation is a global challenge. It is one of the most crucial issue for the reservoir sustainability in the world. Reservoir sedimentation is filling of the reservoir behind a dam with sediment carried into a reservoir by streams. The flow of water from the catchment upstream of a reservoir is capable of eroding the catchment area and of depositing material either upstream of the reservoir or in the still water of the reservoir. The deltaic deposition consists of four part front reach, front set, top set and tail reach due to reservoir operation same of these particular can migrate toward the dam and more sediment are brought into the reservoir by the flows, the deltaic deposition pattern may be changed to the wedged type of deposit. For wide reservoir with lateral width much greater than the width of total lateral width of flow outlets the lateral distribution of sediment deposit may not be uniform. All rivers contain sediments, a river, can be considered a body of flowing sediments as much as one of flowing water. When a river is stilled behind a dam, the sediments it contains sink to the bottom of the reservoir. The proportion of the river's total sediment load captured by a dam is known as its "trap efficiency". As the sediments accumulate in the reservoir, so the dam gradually loses its ability to store water for the purpose, for which it was built. Sedimentation is still probably the most serious technical problem faced by the dam industry in many countries.

Keywords *: Reservoir, sediments, flushing, live capacity and silt free water.*

REPORT OF FLUSHING OPERATION OF PANDOH RESERVOIR

The rate of reservoir sedimentation depends mainly on the size of the reservoir relative to the amount of sediment flowing into it. A reservoir on an extremely muddy river will rapidly lose capacity, whereas a reservoir on a very clear river may take centuries to lose an appreciable amount of storage. The amount of sediments carried into a reservoir is at its highest during floods.

The actual process of sediment deposition is unique to every reservoir and is impossible to predict accurately. In general, the coarse, heavier, sediments, like the gravel and sand, tend to settle out at upper end of the reservoir forming a backwater delta which gradually advances toward the dam. The lighter sediments, i.e. the silt and clay, tend to deposit nearer the dam. Several method by which the life enhancement of storage reservoir can be made are dredging, flushing of sediment from reservoir sediment routing/sluicing.

Flushing sediments through a reservoir has be practiced success fully and found to be inexpensive in many cases. However the great amount of water consumed in the flushing operation. Every reservoir can't flushed successfully due to the number of parameters affecting it like flatter bed slope wider section, higher height of the dam and availability of water required for flushing.

During the monsoon season, weather conditions in the Beas catchment area are continuously monitored on hourly basis. Also the input regarding the forecast information from IMD and NHP of BBMB are received continuously.

The two layers of blank panels were already in position in all the 10 bays, before the start of flushing operation. The material for filling the voids of the concrete blocks on upstream slope of Dam was stacked at Dam site. The Lab Staff was also engaged to take the silt samples during the flushing operation. All the other precautions were also taken as per laid down in the procedure, before the start of the flushing operation.

The Process Flow Chart of Flushing Operation Pandoh Reservoir

1. Information to P.C. Chandigarh & Director Regulation, Member Irrigation., Member Power, C.E. System Operation, S.E. DPH at least four to six hours before start of flushing operation when needed.
2. Sounding of the Intake area and intake pit to know the depth of silt deposited.

3. Reduce Pandoh Baggi Tunnel (PBT) @ 600 Cusec per half an hour.
4. Start hourly silt sampling up to EL 2910 feet. and half hourly silt sampling afterwards.
5. Reduce PRL from 2906 to 2900 feet @ 6 feet per hour.
6. Check for any differential.
7. If differential exist raise PRL to eliminate differential.
8. Reduce PRL from 2900 to free flow conditions app. To EL $\pm$ 2884 feet. @ 4 feet/hour.
9. Continue flushing operation as per weather condition in the catchment area i.e.
   (i) Inflow>40000 cusec
   (ii) Rainfall in the catchment area continued to sustain for > 15 Hours.
10. Stop flushing and restore Baggi Control Works if the inflow increases one lac Cusec.
11. Check up Stream slopes of dam and maintain in case of any damage.
12. Check the levels of the up Stream line of surface settlement points.
13. Stop taking half hourly silt sampling when ppm is approximately equal to the ppm at the start of flushing.
14. Increase PRL to 2900 feet @ 4 feet per hour and give half an hour rest for the settlement of sediments.

Details showing the Silt flushed out during Flushing Operations Since 2000

Year	Date	Duration of Flushing in hours	Discharge Available at the time of Flushing (cusecs)	Silt Flushed Out (Acre feet)	Total quantity of silt flushed out during the year (Acre feet)
2000	17/07/2000	12.30	43565	1314	1314
2001	17-18/07/2001	14.30	38485	1845.30	1845.30
2002	13-14/08/2002	8.30	56446	2800.76	2800.76
2003	Nil	Nil	Nil	Nil	Nil
2004	03-04/08/2004	15.30	32680	2467.80	2467.81
	29-30/06/2005	15.30	43559	3001.01	
2005	18-19/07/2005	14.00	37460	1859.52	
	24-25/08/2005	8.30	23435	529.34	5389.87
	29-30/07/2006	13.00	37460	2188.17	
	28/08/2006 to18/09/2006	Forced Flushing due to Closure of D.P.H			
2006			26884	3354.36	5542.53
2007	Nil	Nil	Nil	Nil	Nil
2008	19-20/09/2008	11.00	50698	3847.50	3847.51
2009	Nil	Nil	Nil	Nil	Nil
2010	09-10/08/2010	16.00	50205	4051.07	4051.07
2011	Nil	Nil	Nil	Nil	Nil
2012	Nil	Nil	Nil	Nil	Nil
2013	07-08/07/2013	16.00	37185	5491.21	5491.21
2014	20-21/07/2014	15.50	53785	5599.73	5599.73
2015	05-06/07/2015	12.00	45000	2102.16	2102.16
	09-10/08/2015	17.30	46500	7849.70	9951.86
2016	02-03/08/2016	15.30	48480	6510.79	6510.79
2017	01-02/08/2017	14.30	56620	5195.42	5195.42
2018	13-14/08/2018	14.00	115350	4811.20	14413.93
	24-25/09/2018	16 hour	116525	9602.73	

15. Increase PRL from 2900 to 2906 feet @ 6 feet per hour.
16. Observe the behaviour of different instruments on upstream and downstream of Pandoh Dam.
17. Restart PBT @ 1000 Cusec per half an hour from zero to 8550 Cusec.
18. Maintain the required PRL as advised by Director Water regulation.

CONCLUSION

Globally there are about 25,000 storage reservoir of different storage capacity, the maximum number of reservoir are in North America and minimum reservoir are in central Asia. World annual storage loss due to sedimentation varies from 0.1 to 2.3% with average annual world storage loss of about 1%. The maximum storage loss is in China i.e. 2.3% whereas minimum storage loss is in UK i.e. 0.1% and the loss of storage at other country are 1.5% in Turkey and 0.46% in India. The storage loss is mainly due to different vegetation cover, topographic and geological conditions of the water shed area due to reduction of reservoir value by sediment deposit, flushing reservoir sediment will receive more attention in future.

Since 1986 the flushing operation of Pandoh Reservoir is being carried out every year when the suitable inflow in the catchment are available. During the year 2018, two nos. flushing operations were carried out when the discharge available was more than one lac cusecs and the silt flushed out was (4811.20+9602.73) i.e. 14413.93 acre feet which is the historical figure since 1986.

Simultaneous flushing of Pandoh Dam and trash cleaning of balancing reservoir, Sundernagar: During the period of high inflows in Pandoh Dam, its flushing is an annual activity. During this operation, water flow towards Sundernagar Balancing Reservoir is stopped, thereby resulting in shutting down of power generation in Dehar Power House (DPH). Similarly, cleaning of trash racks provided at intake of Sundernagar – Satluj Tunnel at Pung, requires operating of Balancing Reservoir at low levels. Earlier, flushing of Pandoh Dam and trash cleaning of Balancing Reservoir at Sundernagar were being undertaken separately resulting into loss of energy generation from DPH. This year on 13th and 14th August, simultaneous cleaning of Trash Racks at the intake of Sundernagar –Satluj Tunnel installed in Balancing Reservoir, at Sundernagar and flushing operation of Pandoh Dam were undertaken. This co-ordination led to power saving on account of the fact that there was no additional period of shut-down and thereby reduced generation for cleaning of Trash racks at intake of Sundernagar-Satluj Tunnel, during the monsoon/paddy season. This year, the modified methodology had resulted in reduced loss of generation during period of flushing operation to the tune of 19.69 LUs vis a vis average generation loss during flushing operations of last three years. Average loss of generation on account of trash cleaning for the last three years comes out to be 98.43 LUs. The same can be considered as nil for the current year as activity happened during sediment flushing operation of Pandoh Dam itself. Therefore, total notional reduction in generation on account of simultaneous operation of flushing and trash cleaning works out to be 118.12 LUs and considering National Average Power Purchase Cost (APPC) of Rs. 3.53/kWh, the notional financial gain of this simultaneous activity comes out to approx. Rs. 417 lac.

REFERENCES

1. ABDELHADI, M.L. (1995), "Environmental and Socio-economic impacts of erosion and sedimentation in North African Countries" Proceedings: sixth International Symposium, River Sedimentation, New Delhi, India. CV. J. Varma and A.R.G. Rao (editors), Published by A.A.Balkema.
2. ALBERTSON, M.L., MALINAS,A., and HOTCHKISS. R., editors (1996), Proceedings of the International Conference on Reservoir Sedimentation, Fort collins, Colorado.
3. AMINI, A, and FOULADI, C. (1985), "Sediment Flushing at the Sefidrud Reservoir", Proceedings: Second International Workshop on alluvial River Problems", Roorkee, India. Published by Central Board of Irrigation and Power, New Delhi.
4. ATKINSON, E., (1996), "The Feasibility of Flushing Sediment from Reservoirs", Report OD 137, HR Wallingford, November.
5. BASSON, G.R. and ROOSEBOOM, Albert, (1996)," Sediment Pass-Through Operations in Reservoirs" in Volume 2 of Albertson et. al. (1996). JOURNAL OF HYDRAULIC RESEARCH, VOL. 37. 1999, NO. 6 755 Downloaded By: [Dewals, Benjamin] At: 12:26 1 July 2010
6. BECHTLER, W. and NUJIA, M. (1996), "Predicting Reservoir Sedimentation with 2D Model FLOODSIM" in Volume 1 of Albertson et al. (1996).
7. BOUCHARD, J.P., MAUREL, F., and PETITJEAN (1996), "Numerical Modeling of Sediment Resuspension in Reservoirs" in Vol 1 of Albertson et al. (1996).
8. CHANG, H.H., HARRISON, L.L., LEE, W. and Tu, S. (1996), "Numerical Modeling for Sediment Pass-Through Reservoirs" Journal of Hydraulic Engineering, ASCE, Vol. 122, No. 7, July.

9. CROWDER, B.M. (1987), "Economic Costs of Reservoir Sedimentation: a Regional Approach to estimating cropland erosion damages", Journal of Soil and Water Coservation, Vol. 42, No.3.
10. DAWANS, P.H., CHARPIE, J., GIEZENDANNER, W., and RUFWENACHT, H.P. (1982) "Le degravement la retenue de Gebidem."Proceedings 14, h Congress on Large Dams, ICOLD, Rio de Janeiro, Brazil.
11. DING, L., and LONG, Y. (1996), "Regulation of Water amd Sediment in Sanmenxia reservoir for Multipurpose Use" Proceedings: Second International Workshop on Alluvial River Problems, Roorkee, India. Published by Central Board of Irrigation and Power, New Delhi.
12. FAN, J., and FAN, S.S. (1996), "Control of Sediment Deposition by Flood Flushing" in Vol. 2 of Albertson et al (1996).
13. FAN, J., and MORRIS, G.L. (1992), "Reservoir Sedimentation II: reservoir Desiltation and Long Term Storage Capacity" Journal of Hydraulic Engineering., ASCE, Vol. 118, No. 3, March.
14. Fox, I., and TARIG, SARDAR (1996), "Development of Sedimentation Delta at Tarbela Reservoir" in Vol. 3 of Albertson etal (1996). _
15. GUAN, Y., RONG, F., and WANG, H. (1991), "A numerical model for sedimentation in Fenhe Reservoir and the adjoining Reaches" International Journal of Sediment Research, IRTCES. Vol. 36, No. 4, April.
16. GUOHAN, D., and ZHENQUI, Z. (1989), "The Erosion of Cohesive Sediment in Retrogressive Erosion in Reservoirs", Proceedings of the 13lh IAHR Congress, Ottawa, Canada.
17. GVELESIANA, L.G. and SHAMAL'TZE; N.P. (1971), "Studies of Storage Work Silting of Hydroelectric Poer Plants in Mountain Rivers and Silt Deposition fighting", Proceedings of the 14lh IAHR Congress, Paris, France, Vol. 5.
18. HAN, Q, and HE, M. (1996), "Sedimentation and Control Measures of Three Gorges Reservoirs" in Vol. 3 of Albertson, etal (1996).
19. HAN Q, HE, M. et al. (1999), Private Communication from the Three Gorges Dam Design Report.
20. HWANG, JING-SANG (1996), "Economics" in Vol. 2 of Albertson, et al. (1996).
21. IRTCES (1985), "Lecture Notes of the Training Course on reservoir Sedimentation." International Research and Training Centre on Erosion and Sedimentation, P.O.Box 366, Beijing, China.
22. JAGGI, A.L. and KASHYAP, B.R. (1984), "Desilting of Baira Reservoir of Baira Siul Project" Irrigation and Power, October.
23. JANSSEN, R.., (1999), "An Experimental Investigation of Flushing Channel Formation during Reservoir Drawdown" dissertation presented to the University of California at Berkeley, in partial fulfillment for the requirements for the degree of Doctor of Philosophy.
24. JOWETT, I., (1984), "Sedimentation in New Zealnad Hydroelectri Schemes." Water Intrernational, 9.
25. KITAMURA, Y. (1995), "Erosion and Transport Processes of Cohesive Sediment in Dam Reservoirs" Journal of Hydroscience and Hydraulic Engineering, Vol. 13, No.I, May.
26. KRUMD1ECK, A., and CHAMOT, P., (1979), "Sediment flushing at the Santo Domingo Reservoir" Water Power and Dam Construction, December.
27. LACEY, G., (1930), "Stable Channels in Alluvium" Minutes of Proc. ICE, 229, United Kingdom.
28 LAI JING-SUNG (1994), "Hydraulic Flushing for reservoir Desiltation" dissertation presented to the University of California at Berkeley, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
29. LAI J.S. and SHEN, H.W., (1996) "Flushing Sediment through Reservoirs" Journal of Hydraulic Research, IAHR, Vol. 24, No.2.
30. MAHMOOD, K. (1987), "Reservoir Sedimentation: Impact, Extent, and Mitigation", World Bank Technical Paper Number 71, The International Bank for Reconstruction and Development.
31. MORRIS, G.L. (1995), "Reservoir Sedimentation and Sustainable Development in India: Problem Scope and Remedial Strategies," Proceedings: Sixth International Symposium, River Sedimentation, New Delhi, India.
32. C.V.J.Varma and A.R.G. Rao (editors). Published by A.A.Balkema, Rotterdam.
33. Morris, G.L. and FAN, J. (1998), "Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoir, and Watersheds for Sustainable Use," McGraw Hill Publishes, New York.
34. RIENOSSAL, K., and SCHNELLE, P., (1982), "Sedimentation of Small Reservoirs in the High Alps", 14lh Congress on Large Dams, ICOLD, Rio De Janeiro, Brazil.
35. SCHEUERLEIN, H., (1987), "Sedimentation of Reservoirs- Methods of Preventing and Techniques of Rehabilitation" First Iranian Symposium on Dam Engineering Tehran, Iran. 756 JOURNAL DE RECHERCHES HYDRAULIQUES. VOL. 37, 1999, NO. 6 Downloaded By: [Dewals, Benjamin] At: 12:26 1 July 2010

36. SEN, S.P., and SRIVASTAVA, (1995), "Flushing of Sediment from Small Reservoirs" Proceedings: Sixth International Symposium, River Sedimentation, New Delhi, India. C.V.J. Varma and A.R.G. Rao (editors). Published by A.A. Balkema, Rotterdam.
37. SHEN, H.W., and LAI, J.S., (1996), "Sustain Reservoir Useful Life by Flushing Sediment". International Journal of sediment Research, IRTCES, Vol. 11, No 3. December.
38. SHIAU, JENG-TZONG, (1997), "Stochastic Analysis and Optimal reservoir Operation during Drought Periods". Dissertation presented to the University of California at Berkeley, in partial fulfillment for the requirements for the Doctor of Philosophy.
39. SHUYOU, C, Duo, F., XINNIAN, L., and JIAYANG, C, (1988), "Mathematical Modeling of Delta Deposits and Retrogressive Erosion in reservoirs," Proceedings of the ASCE National Conference of Hydraulic Engineering, Colorado Springs, Colorado, S.R.Abt and J. Gessler (editors).
40. Swiss National Committee on Large Dams, (1982), General Paper. 14lh Congress on Large DamsICOLD, Rio de Janeiro, Brazil.
41. Tsinghua University (Sedimentation Research Laboratory) and North-west Institute of Hydrotechnical Research (1979), "Reservoir Sedimentation", Water Conservancy and Electric Power Press, (in Chinese).
42. YALIN, M., S., (1992), "River Mechanics", Pergamon Press.
43. YOON, Y., N., (1992), "The State and the Perspective of the Direct Sediment Removal Methods from Reservoirs." International Journal of Sediment Research, Vol.7, No.2.
44. ZHANG C., (1996), "An experimental Study of Clearance of Reservoir Deposition", in Vol. 3 of Albertson et al. (1996).
45. ZHENG C, WANG, J„ and Li, Q. (1995), "Proceedings of the Sixth International Symposium, river Sedimentation, New Delhi, India. C.V.J. Varma and A.R. Rao (editors).
46. ZIEGLER, C.K., and NISBET, B.S. (1995). "Long Term Simulation of Fine-Grained Sediment Transport in Large Reservoir", Journal of Hydraulic Engineering, ASCE, Vol. 121, No.I 1.

Chemical Analysis of Surface Water Quality of River Noyyal Connected Tank in Tirupur District, Tamil Nadu, India

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ABSTRACT

In the developing countries, the most prevalent environmental issue is the adverse effect of fast industrialization on the quantity and quality of surface water bodies. Tirupur city, located on the bank of River Noyyal is recognised all over the world for its textile processing business. The river acts as a sink for varied pollutants like industrial effluents, dyeing waste and sewage. Thus, in order to study the surface water quality of Noyyal River, the present investigation has been designed systematically choosing three sampling stations namely source (S_1), Mangalam (S_2) (before Tirupur) and Kasipalayam (S_3) (after Tirupur). The samples required for various analyses were collected from open wells at Noyyal River basin. After employing suitable methodologies to measure various parameters such as dissolved oxygen (DO), biological oxygen demand (BOD), pH, faecal coliforms, nitrates, phosphate, turbidity and total dissolved solids (TDS), the samples were given National Sanitation Foundation-Water Quality Index (NSF-WQI). A detailed statistical analysis among the water quality parameters has been carried out. A strong correlation was found among the parameters for both the monsoon and summer seasons. Linear regression analysis is adopted to establish an interrelationship between the parameters.

Keywords *: Surface water, Water quality index, Noyyal River, Regression, Correlation coefficient*

INTRODUCTION

Water, a crucial natural resource and a valuable asset, forms the chief constituent of eco-systems. Increasing population, industrialization and urbanization are the key factors for the deterioration of surface and ground water[1-4]. The quantity, quality and availability of drinking water are the predominant issues[4]. Water quality monitoring and decision making on the data is a challenging issue, even though water quality index can throw some light[6]. The surface water bodies are vital source of water for human beings, which are currently under stern environmental stress due to developmental activities. The reasons for the extinction of water bodies are encroachment and pollution[7]. The major cause for surface water pollution is the discharge of effluents from various dyeing industries. According to the central pollution control board in India, the dyeing industry is one of the heavily polluting industries. The quality of surface water in the particular area mainly depends on the nature and extent of the industry, cultivation and other human activities in the catchments. The river system gets affected directly or indirectly by the easy accessibility and dynamic nature of waste disposal[8]. The investigation of water quality at various stations gives information about unsuitable and undesirable changes in water parameter.

The population growth and development of economic activities certainly lead to increase in the demand of water for different purposes. The quality of water is often affected by the quality and quantity of supply that comes from various sources. Therefore, monitoring the problems of water quality becomes a complex process which is associated with evaluation of measured variables[9] and high variability because of the influences of natural and anthropogenic activities[10]. The studies of interrelationship among the different variables are useful in overcoming this complexity. The range of uncertainty related to decision making can be reduced through correlation studies[11-16].

The Noyyal River originates in the Vellingiri hills and passes through Coimbatore, Tirupur, Erode and Karur districts of western Tamil Nadu before its convergence with River Cauvery at Noyyal hamlet in Karur district. In this investigation, to appraise the water quality characteristics of Noyyal River at its source (S_1), places before and after Tirupur (Mangalam (S_2) and Kasipalayam (S_3) have been carried out by using National Sanitation Foundation Water Quality Index (NSF-WQI) method. Also, the regression analysis has been used to derive the interrelationship among various water quality parameters. The regression models provide general information about the quality and quantity of pollution loads of surface water quality based on observed values. This method is also used to identify the variations in water quality parameters within the system.

MATERIALS AND METHODS

Collection of Samples

Surface water samples were collected in polythene bottles thoroughly washed with mild acid. Three stations, one at its source and the remaining two places before and after Tirupur (i.e. Mangalam 2 km upstream of Tirupur and Kasipalayam 5 km downstream of Tirupur) were selected for the study. The samples were collected during two seasonal periods, monsoon season with heavy flow and summer season with scanty flow in the year 2017. The time of collection of samples from the respective stations was 10 am during both the seasons. The methods of collection of samples were different for physico-chemical and biological examinations adopting standard procedures. The instruments were calibrated before use and AR grade chemicals were used.

Methods of Analysis

Digital pH meter was used to measure pH. Winkler's modified titrimetric method was used to measure BOD and DO. The total faecal coliform present in the water was measured using multiple-tube fermentation method and nutrient broth was used to confirm and complete the test. Digital turbidity meter was used to measure turbidity. To determine the total dissolved solids, evaporation method was carried out by using standard procedures and Brucine method was used to determine the nitrate ion. The total phosphate was measured using stannous chloride method following the established procedure[16,17].

Statistical Methods

Interrelationships among physico-chemical characteristics of analysed water samples were established through mean, standard deviation (SD), standard error (SE) and coefficient of variation (CV), correlation coefficient and regression lines[16-18].

RESULTS AND DISCUSSION

Table 1 represents the overall water quality index value of various parameters of the water samples in different seasons. Eight parameters were used to calculate the water quality index of samples. The overall water quality index was calculated by adding the eight resulting values[19].

WQI = 0.19 DO + 0.18 FC + 0.12 pH + 0.12 BOD + 0.11 Phosphate +0.11 Nitrates + 0.09 Turbidity + 0.08 TDS

The life of aquatic organisms mainly depends upon the percentage of dissolved oxygen in the water system[20]. The fish community gets affected particularly during spawning periods due to low percentage of saturation of DO because dissolved oxygen is essential to the respiratory system to breathe[21,22]. The sampling station S_1 is the origin of Noyyal River and it has larger dissolved oxygen value of 97.50% and 95.50% saturation during the rainy and summer seasons, respectively. The DO value starts declining and reaches 40% and 28% saturation during monsoon and summer seasons respectively at Kasipalayam (S_3) as expected. The percentage of dissolved oxygen has decreased from 97.50% to 40% during monsoon season and 95.50% to 28% during summer season due to the liberation of bleaching and dyeing effluents containing organic matter and domestic waste water into the river system especially at Kasipalayam (S_3) leading to depletion of oxygen in water.

Faecal Coliform and pH

The faecal coliform bacteria indicate the existence of disease producing microbes in the water systems[23,24]. The increased counts of faecal coliforms were observed from S_1 to S_3 during both monsoon and summer season. This indicates that certain domestic sewage enters the river stream. At Kasipalayam (S_3), there is comparatively maximum coliform during monsoon and summer seasons owing to discharge of sewage into the water bodies. The corrosive nature of water indicates the lower pH value and higher value of pH results in an unpleasant taste and causes harm to eyes and skin[25]. For drinking water, the pH value should be from 6.5 to 8.5 as per standards prescribed by ICMR and WHO[26, 27]. In this investigation, the observed pH values range from 7.2 to 9.5 [Table 1].

BOD, Phosphate and Nitrate

BOD is a measure of the amount of food for bacteria found in water. In Indian river system, nearly 30 % of BOD is due to industrial activity[28]. The lowest BOD in River Noyyal at source (S_1) was observed as 0.45 mg/l and 0.75 mg/l during monsoon and summer seasons respectively and the highest value was observed in Kasipalayam (S_3)

Table 1 : Physico-chemical characteristics of water samples collected from different stations of River Noyyal during the monsoon and summer season-2017

S. No.	Parameters	Units	Monsoon season			Summer season		
			Source (S_1)	Mangalam (S_2)	Kasipalayam (S_3)	Source (S_1)	Mangalam (S_2)	Kasipalayam (S_3)
1	DO	% saturation	97.50	79	40	95.50	71	28
2	FC	MPN/100 ml	2.00	270	680	3.00	420	750
3	pH	pH units	7.20	7.60	8.50	7.50	8.0	9.50
4	BOD	mg/l	0.45	10.50	19	0.75	15.50	40
5	P	mg/l	0.10	1.80	3.50	0.15	1.50	3.80
6	N	mg/l	0.25	4.0	6.0	0.20	7.00	12
7	Turbidity	NTU	2.50	12	15	2.00	19	20
8	TDS	mg/l	80	485	1250	113	950	2050
Overall WQI			**94.39**	**57.61**	**42.66**	**92.93**	**49.17**	**26.52**

as 19 mg/l and 40 mg/l during monsoon and summer seasons respectively. High level of BOD at Kasipalayam (S_3) indicates the high load of organic matter present in the surface water, which depletes oxygen for its oxidation process. The present study reveals that River Noyyal has been contaminated with high concentration of phosphate ranging from 0.1 mg/l to 3.8 mg/l. Stations S_2 and S_3 showed high phosphate content during both monsoon and summer seasons when compared to the source (S_1). This may be due to the flushing of animal and human waste into water system from poorly or partly treated sewage and some phosphorous containing industrial waste.

Nitrate is one of the severe organic pollutants contributed by nitrogenous fertilizers, human and animal waste and industrial effluents through the biochemical activities of micro-organisms[29]. In the current study, the concentration of nitrate found in the analysed water samples ranges from 0.25 mg/l to 12 mg/l. The amount of nitrate at Kasipalayam (S_3) was 6 mg/l to 12 mg/l compared to Mangalam (S_2), which was 4 mg/l to 7 mg/l and source at it was 0.25 mg/l to 0.20 mg/l during monsoon and summer seasons respectively. High concentration of nitrate in water may lead to eutrophication of water bodies besides causing health problems in infants and animals.

Turbidity and Total Dissolved Solids

Turbidity is the main issue during all the analysed periods. The values of turbidity measurements are shown in Table 1. The water at source (S_1) point of Noyyal River has been found to have a low turbidity during monsoon and summer seasons, while other samples at S_2 and S_3 show high values. Total Dissolved Solids is the indication of suspended solids in a water body. Total dissolved solids (TDS) comprises of salts such as carbonates, bicarbonates, sulphates, chlorides phosphates, and magnesium, nitrates, calcium, potassium, iron sodium, and small quantity of organic matter. For potable water, the permissible value of TDS should be less than 500 mg/l recommended by WHO[30]. In this present study, the lowest value of TDS was observed at S_1 and the highest value was found at S_3.

Statistical Analyses

The statistical parameters like mean, range, standard deviation, standard error, coefficient of variation, correlation and regression are calculated for the observed data under study and are presented in Tables 2-9. Table 2 shows some of the important statistical characteristic of water samples. The coefficient of variation observed in the monsoon season for pH is 8.57 %. It shows that the variation of pH among its measured values at different locations is very narrow. Also, the observed coefficient of variation for DO was found to be 40.67% which is considered to be moderate. The values of other water quality parameters like FC, BOD, P, N, TUR and TDS were found to be high. Table 3 shows the coefficient of variation observed in the summer season. Coefficient of correlation between different water quality parameters for two seasons namely monsoon and summer are presented in Table 4 and 5 respectively. Similarly, the correlation coefficients between the stations are shown in Table 6.

In monsoon season, it is observed that correlation coefficient between water quality parameters are very high (positively or negatively) around 0.99. This proved that the best fit interrelationship between parameters can be established. pH showed high negative correlation with DO. A linear relationship between pH and DO has been established by regression analysis. DO was found to have high negatively correlation (r = -0.99963) with TDS, TDS depicted significant correlation (r = 0.99846) with FC and FC shows strong positive correlation with phosphate. Similarly, other parameters were found to be strongly positively correlated with one another such as BOD, N and TUR. Linear regression analysis has been carried out among these parameters and presented in Table 7. It is found that the percentage of error between the observed and expected values are less than 8%.

In summer season, it is noted that the correlation between BOD and P is positively strongly correlated (r = 0.99998). So, starting with BOD, regression analysis is carried out for the remaining parameters. It is observed that all the parameters are highly correlated with one another. Linear interrelationship among all the parameters considered for study has been established and presented in Table 8. It is noted that the percentage of error between the observed and expected values are less than 9% in the summer season.

A linear relation between the values of parameters in station 3 in terms of values of parameters in station 2 is presented in Table 9. From the relationships, one can predict values of parameter in station 3 through the values of parameters in station 2. The error occurred in this prediction is approximately less than 7%.

Table 2 : Statistical analysis of water samples during the monsoon season-2017

Parameter	Max	Min	Range	Mean	SD	SE	CV%
DO	97.50000	40.00000	57.50000	72.16667	29.35274	16.94681	40.67
FC	680.00000	2.00000	678.00000	317.33333	341.46937	197.14743	107.61
pH	8.50000	7.20000	1.30000	7.76667	0.66583	0.38442	8.57
BOD	19.00000	0.45000	18.55000	9.98333	9.28579	5.36115	93.01
P	3.50000	0.10000	3.40000	1.80000	1.70000	0.98150	94.44
N	6.00000	0.25000	5.75000	3.41667	2.91905	1.68531	85.44
TUR	15.00000	2.00000	13.00000	9.66667	6.80686	3.92994	70.42
TDS	1250.00000	80.00000	1170.00000	605.00000	594.15907	343.03790	98.21

Table 3 : Statistical analysis of water samples during the summer season-2017

Parameter	Max	Min	Range	Mean	SD	SE	CV%
DO	95.50000	28.00000	67.50000	64.83333	34.16992	19.72801	52.70
FC	750.00000	3.00000	747.00000	391.00000	374.34343	216.12728	95.74
pH	9.50000	7.50000	2.00000	8.33333	1.04083	0.60093	12.49
BOD	40.00000	0.75000	39.25000	18.75000	19.82580	11.44643	105.74
P	3.80000	0.15000	3.65000	1.81667	1.84549	1.06549	101.59
N	12.00000	0.20000	11.80000	6.40000	5.92284	3.41955	92.54
TUR	20.00000	1.75000	18.25000	13.58333	10.26016	5.92370	75.53
TDS	2050.00000	113.00000	1937.00000	1037.66667	971.47122	560.87917	93.62

Table 4 : Correlation between physico-chemical characteristics of surface water during the monsoon season-2017

Parameters	DO	FC	pH	BOD	P	N	TUR	TDS
DO	1							
FC	– 0.99659	1						
pH	– 0.99988	0.99518	1					
BOD	– 0.96861	0.98583	0.96464	1				
P	– 0.97947	0.99277	0.97622	0.99884	1			
N	–0.92979	0.95701	0.92397	0.99211	0.98491	1		
TUR	– 0.87546	0.91238	0.86786	0.96811	0.95492	0.99189	1	
TDS	– 0.99963	0.99846	0.99909	0.97501	0.98458	0.93946	0.88827	1

Table 5 : Correlation between physico-chemical characteristics of surface water during the summer season-2017

Parameters	DO	FC	pH	BOD	P	N	TUR	TDS
DO	1							
FC	– 0.97500	1						
pH	– 0.99231	0.94000	1					
BOD	– 0.99990	0.97812	0.99041	1				
P	– 0.99997	0.976670	0.99132	0.99998	1			
N	– 0.97019	0.99979	0.93273	0.97360	0.97205	1		
TUR	– 0.80698	0.91803	0.72767	0.81545	0.81155	0.92604	1	
TDS	– 0.99690	0.98945	0.97951	0.99794	0.99749	0.98624	0.85091	1

Table 6 : Correlation between various stations of surface water from River Noyyal during the monsoon and summer season-2017

Season	Monsoon			Summer		
Stations	Station 1	Station 2	Station 3	Station 1	Station 2	Station 3
Station 1	1			1		
Station 2	0.52766	1		0.65654	1	
Station 3	0.43562	0.99297	1	0.64414	0.99614	1

Table 7 : Linear correlation coefficient and regression equation for some pairs of parameters (monsoon season-2017)

Pair of Parameters	Correlation Coefficient	Regression Coefficient		Regression Equation
		a	b	
pH and DO	– 0.99988	414.51	– 44.08	DO = 414.51– 44.08 pH
DO and TDS	– 0.99963	2065.26	– 20.23	TDS = 2065.26 – 20.23 DO
TDS and FC	0.99846	– 29.83	0.5738	FC = – 29.83 + 0.5738 TDS
FC and P	0.99277	0.2316	0.0049	P = 0.2316 + 0.0049 FC
P and BOD	0.99887	0.1627	5.4559	BOD = 0.1627 + 5.4559 P
BOD and N	0.99211	– 0.7996	3.1559	N = – 0.7996 + 3.1559 BOD
N and TUR	0.99189	1.7641	2.3130	TUR= 1.7641 + 2.3130 N

Table 8 : Linear correlation coefficient and regression equation for some pairs of parameters (summer season-2017)

Pair of Parameters	Correlation Coefficient	Regression Coefficient		Regression Equation
		a	b	
BOD and P	0.99994	0.0714	0.0931	P = 0.0713 + 0.0931BOD
P and DO	– 0.99997	98.47	– 18.51	DO = 98.47 – 18.51P
DO and TDS	– 0.99690	2875.21	– 28.34	TDS = 2875.21 – 28.34 DO
TDS and FC	0.98945	–4.63	0.3813	FC = 4.63 + 0.3813TDS
FC and N	0.99979	0.2149	0.0158	N = 0.2149 + 0.0158 FC
N and pH	0.93273	7.28	0.1639	pH = 7.28 + 0.1639 N
pH and TUR	0.72767	– 46.19	7.17	TUR = – 46.19 + 7.17 pH

Table 9 : Linear correlation coefficient and regression equation between stations during the monsoon and summer seasons-2017

Season	Pair of Stations	Correlation Coefficient	Regression Coefficient		Regression Equation
			a	b	
Monsoon	S_2 and S_3	0.99297	– 30.63	2.61	$S_3 = -30.63 + 2.61S_2$
Summer	S_2 and S_3	0.99614	– 34.67	2.14	$S_3 = -34.67 + 2.14\ S_2$

CONCLUSION

The surface water samples of Noyyal River in Tirupur city were analyzed systematically by various parameters, which revealed that majority of the parameters exceed the standard limits for drinking water. The high faecal coliforms count in the river renders the water unsuitable for domestic use. Higher level of TDS in water samples is due to the release of high concentrations of salt solutions from dyeing and bleaching effluents in to the river. The increased value of BOD indirectly shows heavy organic load in Noyyal River. From the analysis, it has been observed that the textile and dyeing effluents from the industrial area of Tirupur region has its impact on the surface water quality of Noyyal River. So, it is very much essential to monitor the river at regular intervals and recommend suitable remedial measures like setting up the common treatment plant to treat the waste before discharging into the river. This strategy may be useful to control the pollution of the river and maintain the standards of the water quality. Statistical analysis shows that all the parameters under consideration are strongly correlated (positive or negative) indicating the best linear interrelationship between parameters. This statistical analysis may be useful in understanding the water source management for the study area.

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REFERENCES

1. S.F. Babaei, A.H. Hassani, A. Torabian, A.R. Karbassi, and L.F. Hosseinzadeh, African J. Biotech., 10, 1025 (2011).
2. M. Dhanasekarapandian, S. Chandran, V. Kumar, Water and Energy Inter., 60r, 49 (2017).
3. S. Sangeetha, M. Krishnaveni, Water and Energy Inter., 60r, 67 (2017).
4. P.S. Kumar, P. Balamurugan, Water and Energy Inter., 61r, 59 (2018).
5. S. Dahiya, B. Singh, S. Gaur, V.K. Garg, and H.S. Kushwaha, J. Hazard. Mater., 147, 938 (2007).
6. K. Parmar, and V. Parmar, J. Environ. Sci., 1, 77 (2010).
7. K. Yogendra, and E.T. Puttaiah, Proceedings of Taal 2007, The 12th World Lake Conference, 2008, p. 342–346.
8. S. Daneshmand, B.K. Huabujang, H. Moayedi, and A.M. Ali Thamer, Eng. J., 15, 41 (2011).
9. H. Boyacioglu, Water S.A., 32, 389 (2006).
10. V. Simeonov, J.W. Einax, I. Stanimirova and J. Kraft, Anal. Bioanal. Chem., 374, 898 (2002).
11. F. Maqbool, A.H. Malik, A.Z. Bhatti, A. Pervez and M. Sueman, Pak. J. Agri. Sci., 49, 95 (2012).
12. K.K. Yadav, N. Gupta, V. Kumar, S. Arya and D. Singh, Recent Res. in Sci. and Technol., 4, 51 (2012).
13. A.U. Rahman, and M. Owaischughtai, African J. Environ. Sci. and Technol., 8, 86 (2014).
14. G. Sudhakar, G. Swarnalatha, Z. Vishnuvardhan and D. Harika, IOSR, J. Environ. Sci. Toxicol. and Food Technol., 8, 27 (2014).
15. M.M. Heydari, A. Abasi, S.M. Rohani, and S.M.A. Ali Hosseini, J. Sci. Res., 13, 1238 (2013).
16. K. Jothivenkadachalam, A. Nithya, and S. Chandramohan. Rasayan J. Chem., 3, 649 (2010).
17. American Public Health Association (APHA), Standard methods for the examination of water and waste water 20th ed., Washington D.C., USA, 1998.
18. M. Jayaraj, K. Ramakrishnan, S. Arunachalam and P.N. Magudeswaran, Asian J. Chem., 28, 1469 (2016).
19. P.N. Magudeswaran, PhD Thesis, (Chemistry), Bharathiyar University, Coimbatore, Tamil Nadu, India, 2004.
20. A.K. Gupta, K. Mishra, P. Kumar, C. Singh, and S. Srivastava, India Plant Arch., 11, 297 (2011).
21. A.A. Jammel, Poll. Res., 17, 111 (1998).
22. J.H. Ellis, Water Resour. Res., 23, 2227 (1987).
23. B. Genthe, and J. Seager, WRC report no.562/1/96, Water research commission. Pretoria, South Africa, 1996.
24. M. Zamxaka, G. Pironcheva, and N.Y.O. Muyima, Water S.A., 30, 333 (2004).
25. G.S. Rao and G.N. Rao, J. Environ. Sci. Eng., 52, 137 (2010).
26. Guidelines for drinking water quality, 4th edition, incorporating the 1st addendum, 2017.
27. ICMR, Manual of standards of quality of drinking water supplies, 1975.
28. D. Moherjee, M. Chattopadhyay and S.C. Lahiri, The Environmentalist., 13, 199 (1993).
29. S.K. Agarwal, APH publication, Water pollution New Delhi, India, 2005.
30. WHO, Guidelines for drinking Water Quality, Geneva, Switzerland, 2004.

Application of Constructed Wetlands for Different Wastewater Treatment in Tropical Regions : A Review

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ABSTRACT

Constructed wetlands (CWs) system is currently regarded as established eco-technologies to treat various types of wastewater in developed nations over the past decades due to virtue of its simplicity, cost effectiveness, based on natural processes, eco-friendly and green development. With the goal of promoting green and sustainable systems to support human well-being as well as favourable with sustaining environmental management systems, the application of CWs has become more relevant. The application of CWs is very significant especially in tropical and sub-tropical regions in developing countries, which produced satisfactory treatment efficiencies than to those in temperate regions, due to availing facility of very conducive to higher biological activity and productivity. The present paper therefore highlights the concept of CWs with removal mechanism, recent practice, applications, and research of treatment wetlands especially for tropical regions in developing countries. In the present review, the performance of contaminant removal shown to be very competent and consistent across all types of CWs. The hybrid systems appeared more efficient in the removal of TSS (92%), COD (81%), NH_4-N (76%), NO_3-N (78%) and TN (73%), as compared to other types of CWs. VSSF CWs removed pollutants more efficiently than HSSF CWs in terms of TSS (87%>71%), BOD (90%>81%), NO_3-N (62%>44%) and TN (57%>48%), but HSSF CWs showed better removal for COD (76%>62%), TP (65%>61%) and NH_4-N (66%>58%) as compared to VSSF CWs. Compared to other types of CWs, both HSSF and VSSF CWs showed superior TP removal. VSSF systems showed the best BOD removal (90%) among all the CWs types.

Keywords **:** *Constructed Wetlands; Wastewater Treatment; Developing Countries; Tropical Region; Removal Mechanism*

1. INTRODUCTION

Worldwide, there is a growing concern to face the emerging water crisis. The challenge is more serious in countries of rising economies such as in India where water demand and consumption rates are very high for its agricultural, domestic and industrial uses. Consequently, discharging of 80-90% untreated wastewater directly into fresh water reservoirs like rivers, lakes and ponds is a common practices, in developing contries, which made the problem more severe (UN Water 2008). However, during the past two decades, the governments in these countries have realized and giving attention to address the water challenges including formulation and implementation of pollution abatement schemes with aim to conserve their water bodies. Additionally, there is a growing focus on water reuse and recycle opportunities in these countries. However, due to lack of resources, and policy hindrances, the wastewater treatment schemes are limited to large and medium sized urban centres. In the tropical regions in developing countreis like India, where about 70% of its population lives in the rural areas, there is an urgent need to address this neglected sector which is contributing point source water pollution to a greater extent.

As per CPCB (2016), India is generated approximately 61754 MLD (million litres per day) of municipal wastewater from towns and cities. Out of which, about 22963 MLD is treated, thus 62% finds its way untreated directly into surface water. The discharge of untreated wastewater poses threat to receiving water bodies, humans and animals. The severity of pollution of major Indian rivers like Ganges, Yamuna, Gomti, Krishna and many more has alarmed the government and thus there is a growing concern to include in the overall development strategy to focus the rural areas as well (Chaturvedi et al. 2014; Kumar et al. 2015).

High-rate, and energy intensive wastewater treatment systems like Activated Sludge Process (ASP), Sequencing Batch Reactor (SBR), Moving Bed-Bioreactor (MBBR), Up-flow Anaerobic Sludge Blanket (UASB) etc. are not appropriate methods for such quality of wastewater (Kadlec and Wallace 2009; Wen et al. 2011; Zhang et al. 2015). These methods require large investments, and high operation, and maintenance costs. Therefore, cost-effective, sustainable and easy to operate, and maintain methods, may be the aternative choice of treatment for such tropical regions in developing countries.

2. CONSTRUCTED WETLANDS

Owing to simplicity, low capital investment, easy to operate and maintain and sustainability aspects, the constructed wetlands (CWs) technology offers enormous potential in dealing with medium to low strength wastewater in India and similar regions.

Constructed wetlands (CWs), are man made or artificial or engineered systems designed, and constructed to utilize the natural functions, including wetland vegetation, soil media, and their associated microbial associated assemblages, for wastewater treatment within a more controlled environment (Kadlec and Knight 1996).

With the advantages of their high pollutant removal efficiency, easy to operate and low maintenance, cost-effectiveness, high potential for water and nutrient reuse, tolerance to high variability, and function as significant wildlife habitat, CWs have been accepted as a sustainable wastewater management option, for tropical and subtropical developing countries (Kadlec and Wallace 2008; Zhang et al. 2015). Although, CWs have been commonly used to treat domestic or municipal wastewater in tropical countries (Zhang et al. 2015; Jinadasa et al. 2006), recently, the application of CWs has been increasingly extended to address other types of wastewaters including industrial wastewaters, agricultural wastewaters, stormwater runoff, hospital wastewaters, lakewaters and winery wastewater (Zhang et al. 2015; Kadlec and Wallace 2009) Moreover, the removal of wastewater parameters such as the BOD, COD, TSS, fecal indicator bacteria and pathogens, nitrogen and phosphorus, and heavy metals, has been interest of comprehensive research in both, tropical and subtropical climates (Zhang et al. 2015; Dan et al. 2011). Furthermore, the evaluation of the removal performance of a wide range of micro-pollutants (like pharmaceutical and personal care products etc) in tropical regions has also been recently reported (Zhang et al. 2011, 2012). The removal efficiencies of CWs system varies considerably, from system to system, as well as within the same system (Zhang et al. 2015). The processes invoved in CWs system for pollutants removal occured by micro-organism, vegetation and soil matrix, as well as interactions between each other. The pollutant removal efficiency in CWs system depends on wastewater application rate, organic loading rate (OLR), hydrologic regime, hydraulic retention time (HRT), operational mode, and vegetation type (Kadlec and Wallace, 2008).

2.1 Types of Constructed Wetlands

According to the water flow regime and the type of macrophytic growth, CWs may be classified into three groups: free water surface flow (FWSF), subsurface flow (SSF), and hybrid systems (Kadlec and Knight, 1996) (Fig. 1).

2.1.1 *Free Water Surface Flow CWs*

In FWSF CWs, water flowing over vegetation media, mainly mineral (i.e. sandy) and organic (peat) soils underbeneath the vegetation (Fig. 1a). Vegetation are used mainly marsh plants, such as *Typha* and *Scirpus* including other aquatic vegetation like, floating and submerged, and wetland shrubs, and trees. FWSF CWs vary dramatically in size, from less than 1 ha to greater than 1,000 ha. They offer ecological, and engineering benefit, and commonly used for treating agricultural and urban runoff.

2.1.2 *Subsurface Flow CWs*

SSF CWs are one of the most common types of wetland systems used throughout the world. SSF CWs differ from FWS CWs in that they incorporate a rock or gravel matrix so that the wastewater is passed through in a horizontal or vertical fashion. They consist of beds that are usually dug into the ground, lined, filled with a granular medium, and planted with emergent macrophytes such as *phragmites australis, canna, iris pseudacorus* and *typha latifolia* etc. Wastewater flows through the granular medium, and comes into contact with biofilms, plant roots, and rhizomes. SSF CWs are mainly designed to treat primary settled wastewater, although, they are very commonly used to improve the quality of secondary effluents. They continue to provide effective treatment of most wastewater constituents through the winter in temperate climates. Contaminants are removed from wastewater in SSF CWs by physical, chemical and biological processes (Vymazal, 2005). SSF CWs are further subdivided into two types, horizontal subsurface flow (HSSF) and vertical subsurface flow (VSSF) CWs. In HSSF CWs wastewater is maintained at a constant depth and flows horizontally below the surface along the length through granular medium (Zhang et al. 2015). In VSSF CWs wastewater is distributed over the surface of the wetland and trickles downwards through the granular medium (**Fig. 1b** and **Fig. 1c**).

2.1.3 *Hybrid CWs*

Two or more different types of wetland systems are primarily combined to form hybrid wetlands to get higher removal of TN. It is comprised of VF & HF wetland systems that are arranged in a two-stage pattern to achieve higher treatment efficiency and is most widely used in Europe (Vymazal 2005; Kadlec and Wallace

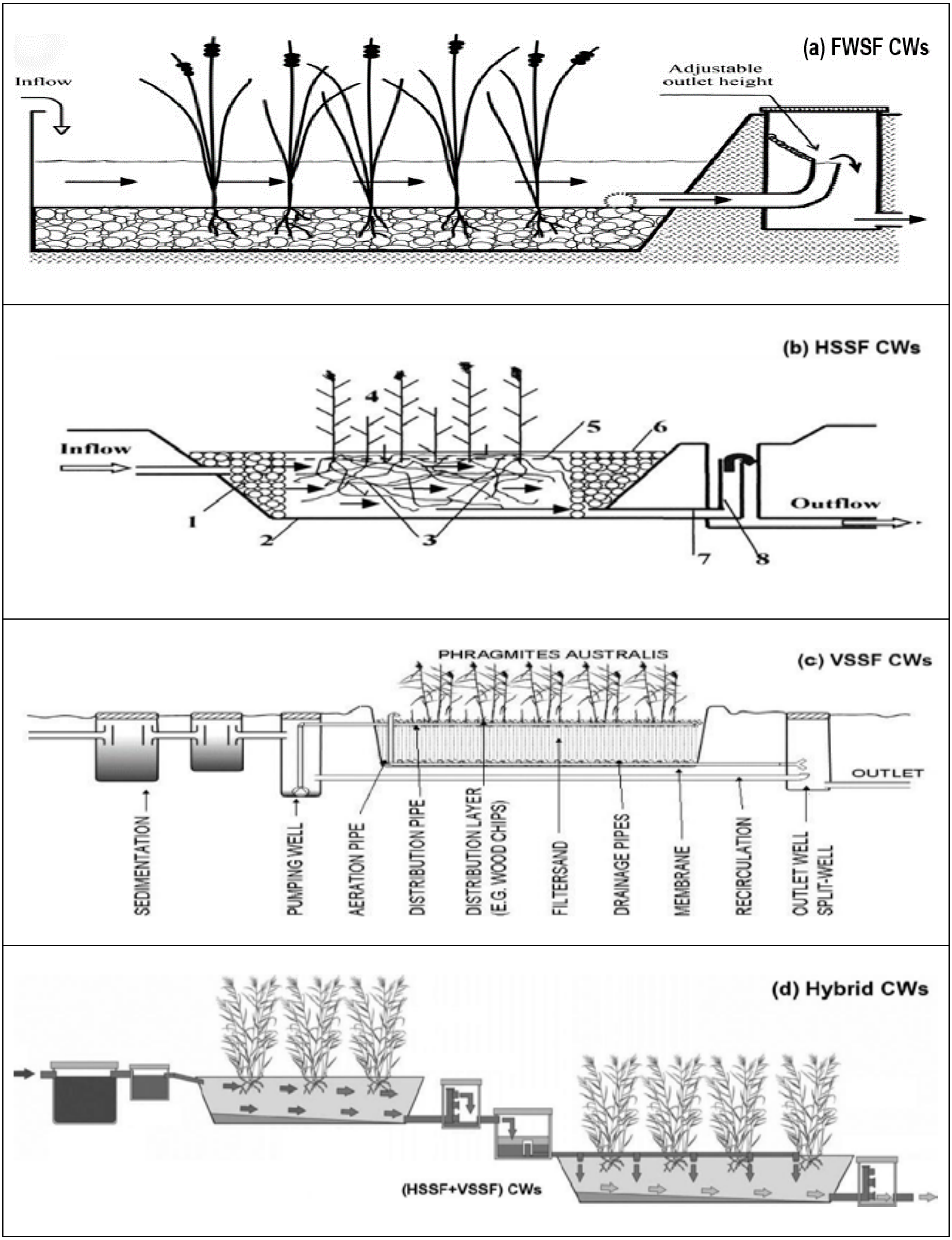

Fig. 1 : Schematic layout of a different types of constructed wetlands. (a): FWSF CWs (Wang et al. 2018); (b) & (c): HSSF CWs and VSSF CWs, respectively. 1: inflow distribution zone filled with large stones; 2: impermeable layer; 3: filtration material; 4: vegetation; 5: water level in the bed; 6: outflow collection zone; 7: drainage pipe; 8: outflow structure with water level adjustment (Vymazal, 2010) (d): Hybrid CWs system (Masi and Martinuzzi, 2007).

2009). Due to their inability to provide both aerobic and anaerobic conditions simultaneously in the single-stage CWs, it can not achieve high removal of total nitrogen (Vymazal, 2007). Individually, HSSF CWs can provide good conditions for denitrification and the ability to nitrify ammonia is however very limited. In contrast, VSSF CWs can remove NH_3-N successfully, but denitrification hardly takes place in these systems. In this regard then, various types of CWs may be combined with one another in order to leverage the strength of each type of individual system. As many types of wastewaters are difficult to treat in a single stage system, systems that consist of various types of CWs arranged in series have been successfully introduced (Fig. 1d).

2.2 Removal Mechanism of Constructed Wetlands

2.2.1 *Nitrogen Removal*

In wastewaters nitrogen exists as organic and inorganic. Common nitrogen removal routes in CWs include ammonification, nitrification, denitrification, partial nitrification-denitrification, plant uptake, biomass assimilation, and adsorption (Kadlec and Wallace, 2009; Saeed and Sun, 2012). Moreover, novel nitrogen removal routes such as Anammox (Anaerobic ammonium oxidation) and Canon (Completely autotrophic nitrogen removal over nitrite) processes had also been reported in CWs (Saeed and Sun, 2017). The following subsections illustrate the basic mechanisms and principles of common nitrogen removal routes in CWs system.

2.2.2 *Ammonification*

In ammonification process, the organic nitrogen is converted into inorganic NH_4-N. The inverse process i.e. the conversion of inorganic NH_4-N into organic nitrogen is referred to as assimilation.

2.2.3 *Nitrification and Denitrification*

Denitrification	$NO_3^- \Rightarrow NO_2^- \Rightarrow NO \Rightarrow N_2O \Rightarrow N_2$
Nitrification	$NH_4^+ \Rightarrow NO_2OH \Rightarrow [NOH] \Rightarrow NO_2^- \Rightarrow NO_3^-$

Fig. 2 : Intermediate products in nitrification and denitrification processes

Nitrification is a two-step process, inorganic ammonium nitrogen (NH_4-N) is oxidized to nitrite nitrogen (NO_2-N) by a bacterial group commonly referred to as Nitrosomonas. Subsequently, NO_2-N is further oxidized into nitrate nitrogen (NO_3-N) by another bacterial group, referred to as Nitrobacter. In this processes, other microbial groups such as Nitrosocystis, Nitrospira, and Nitrococcus are also involved during such transformations that exhibit similar metabolism of Nitrosomonas and Nitrobacter groups (Vymazal 1995, 2007).

Denitrification process, the last step of classical nitrogen removal, is a microbiological route where N oxides act as terminal electron acceptors and organic compounds serve as electron donors (Vymazal, 1995). Denitrification process generates alkalinity; it occurs in anoxic-anaerobic environments and in the presence of facultative biomass, such as Bacillus, Enterobacter, Micrococcus, Pseudomonas, and Spirillum (Kadlec and Wallace, 2009; Vymazal 2007).

2.2.4 *Partial Nitrification and Denitrification*

The main principle of partial nitrification and denitrification process is metabolism of ammonium and nitrite oxidizers which is depends on variation of temperature (decrease and increase). At below 20°C temperature, nitrite oxidation proceeds at a higher rate, when compared with ammonium oxidation. Thus, when the temperature is <20°C, it is generally impossible to limit nitrite oxidation. However, at temperatures greater than 20°C, ammonium oxidation rates are higher than nitrite oxidation rates, resulting in increase of nitrite concentrations, which is the basic principle of partial nitrification (Haandel and Lubbe, 2007; Saeed and Sun 2017). Partial nitrification process (in biological system) is dependent on intermittent aerobic-anoxic phases. In intermittent aerobic phase ammonium is partly converted to nitrite, such intermittent aerobic phase is followed by anoxic/anaerobic phase that hinders oxidation of nitrite to nitrate. Produced nitrite (during partial aeration phase) is denitrified in the absence of nitrate and the presence of organic compounds in the wastewater. In VSSF CWs, predominant aerobic conditions could hinder partial nitrification. However, HSSF CWs could support partial nitrification, if provided with intermittent aeration (Saeed and Sun 2012, 2017).

2.2.5 *Biomass Assimilation*

Biomass assimilation occurs through incorporation of NH_4-N in the heterotrophic biomass cells to fulfill nutrient requirements. Althouhg, N is a major component (12.4%) of biomass cell ($C_5H_7O_2N$), immobilization of NH_4-N into biomass cell could be an important route along with nitrification, particularly in wetland systems where higher organic removal rates are observed. Higher organic removal rates gives larger production of biomass, which might increase NH_4-N immobilization into biomass cells. Considering N component amount in biomass cell (i.e. 12.4%), 1 g BOD removal could promote 0.074 g NH_4-N immobilization into cell biomass in wetland system (Kadlec and Wallace, 2009; Saeed and Sun, 2012).

2.2.6 *Uptake by Plants*

Plants are one of the most important components of CWs system. They provide attachment sites and supply oxygen via roots inside wetland media, thereby accelerating the growth of biofilms (Saeed and Sun, 2012, 2017). Oxygen supply from the roots of *Phragmites* had been quantified between 0.02 and 0.8 g O_2/m^2 (Bavor et al. 1988; Brix and Schierup 1990). Furthermore, such root network also provides organic C (via secretion and decomposition) to support denitrification process in wetland systems (Saeed and Sun, 2017). Nitrogen uptake by plants depends upon configurations, influent wastewater characteristics, input loadings, and environmental parameters (Kadlec and Wallace, 2009). Although, many comparative research studies between planted and unplanted wetlands clearly demonstrated higher removal of N indicating the importance of plants in wetland systems (Saeed and Sun, 2017).

2.2.7 *Removal of Organics*

Wastewater organic contents both biodegradable and nonbiodegradable forms. Each of these two forms, is further divided into two namely particulate and dissolved organics. In a biological system, particulates (biodegradable/nonbiodegradable) are generally removed by physical processes such as filtration and sedimentation (Kadlec and Wallace 2009). In a wetland reactor, organics are biologically degraded via aerobic and anaerobic routes as described in the following subsections. In aerobic degradation (of organic compounds), aerobic chemo-heterotrophs oxidize organic compounds in the presence of oxygen and produce CO_2, NH_3, and other stable chemical compounds. Anaerobic organic is accomplished in the absence of oxygen through four sequential steps, such as (i) hydrolysis, (ii) acidification, (iii) acetogenesis, and (iv) methanogenesis (Vymazal 2007; Saeed and Sun, 2017).

2.2.8 *Media Adsorption*

Adsorption of ammonia due to media is controlled by cation exchange properties of the substrate components and NH_4^+ ions of the bulk wastewater. Although, the limitations of such adsorption process could be attributed to: (i) in aerobic conditions the adsorbed ammonia could be nitrified by the attached nitrifiers (on media surface) followed by release of the produced nitrate into wastewater, thus increasing nitrate concentrations; and (ii) release of the adsorbed ammonia (from the media) into wastewater column, when ammonia content (of wastewater) is lower (Vymazal 2007; Saeed and Sun 2012).

2.2.9 *Removal of Phosphorus*

Phosphorus in wastewater is mainly available in the form of orthophosphate, polyphosphate, and organic phosphate. Orthophosphates (i.e. PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, H_3PO_4) can be degraded by biological process and polyphosphates often undergo hydrolysis process. Wastewaters containing organic phosphates are commonly produced by industrial. Removal of phosphates can be achieved via (i) chemical precipitation and (ii) biological metabolism (Kadlec and Wallace 2009). However, this section focuses on chemical removal of phosphorus that is commonly observed in wetlands (Chemical removal of phosphorus, generally achieved through precipitation of phosphorus with metals salts such as alum, sodium aluminate, ferric chloride, and lime. In CWs, removal of phosphorus is mainly achieved through adsorption or precipitation in the filter materials, rich with Ca/Fe/Al contents. Long-time operation of such specific media would result in substrate saturation (with P), thereby requiring periodical replacement for maintaining stable P removals (Vymazal 2007; Saeed and Sun 2017).

3. PERFORMANCE OF CONSTRUCTED WETLANDS

3.1 Contaminant Removal in Free Water Surface Constructed Wetlands (FWSF CWs)

FWS CWs treatment executes a broad spectrum of biological characteristics that are capable of removing various constituents for water quality improvement, and have been applied to treat wastewater at different stages and from different sources (Kadlec and Wallace, 2008). In particular, they provide a potentially effective buffer between tertiary wastewater treatment plants and natural waterways (Zhang et al. 2015; Vymazal 2007). Therefore, FWS CWs may be a viable option for the ecological restoration of polluted rivers and lakes. A summary of treetment efficiencies of free water surface flow (FWSF) CWs in tropical regions is shown in Table 1. FWSF CWs can effectively remove TSS (70.1%), BOD (77.2%) and COD (72.3%).

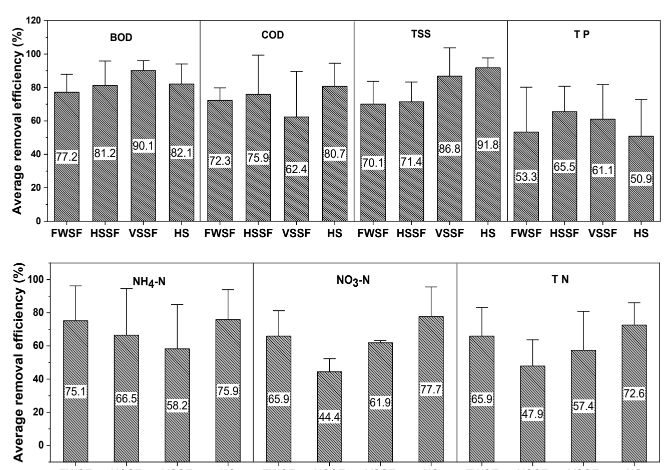

Fig. 3 : Removal efficiencies of pollutants for different CWs systems

The removal of NH_4-N (75.1%), NO_3-N (65.9%) and total nitrogen (TN) is also reliable (65.9%). The removal of total phosphorus (TP) is rather variable, ranging from 19% to 84.3%.

3.2 Contaminant Removal in Susurface Flow Constructed Wetlands (SSF CWs)

Tables 2 and 3 summaries of the treatment parameters and efficiencies for HSSF and VSSF CWs systems in both tropical regions. Both HSSF (74.37%) and VSSF (86.69%) CWs show very efficient removal performance for TSS. VSSF CWs (90.11%) show higher removal of BOD compared to HSSF CWs (81.20%), while COD removal was better in HSSF CWs (75.87%) than that in VSSF CWs (62.36%). The high removal rate for BOD and COD, may be attributed to filtration or sedimentation of solids, as well as degradation by microorganisms. VSSF CWs system is expected to obtained better removal than HF CWs for BOD, due to dominant aerobic environment because of intermittently loaded and unsaturated flow

Table 1 : A summary of treatment efficiencies of free water surface flow (FWSF) CWs in tropical regions

Region	WW	Removal Efficiency (%)							Plants Species	Reference
		TSS	BOD	COD	NH_4-N	NO_3-N	TN	TP		
Sri Lanka	MW	71.9	68.2	-	74.4	50	88.5	19	Scirpus grossus, Typha angustifolia	Jinadasa et al. (2006)
Taiwan	IW	81	89	61	-	85	46	35	Pistia stratiotes, Phragmites communis	Chen et al. (2006)
Thailand	AR	46.5	74.3	-	75.4	-	-	44.9	Typha angustifolia	Klomjek and Nitisoravut (2005)
Kenya	SW	76	-	-	36	-	-	29	Cyperus papyrus, Echinochloa, pyramidalis	Tonderski (2007)
Spain	LW	75	-	-	78.07	58	52	65	Cattails, Rushes	Martín et al. (2013)
Chaina	MW	-	-	76	93	-	64	35.87	Phragmites australis	Wu et al. (2016)
		-	-	75	94	-	60	58	Cyperus rotundus	
		-	-	77	94	-	85	49	Zizania caduciflora	
Malaysia	SR	-	-	-	-	70.7	-	84.3	Phragmites karka, Lepironia articulata	Sim et al. (2008)
Average removal (%)		70.1	77.2	72.3	75.1	65.9	65.9	53.3	-	-

Table 2 : A summary of treatment efficiencies of horizontal subsurface flow (HSSF) CWs in tropical regions

Region	WW	Removal Efficiency (%)							Plants Species	Reference
		TSS	BOD	COD	NH_4-N	NO_3-N	TN	TP		
Egypt	BW	89.0	86.4	83.5	-	-	69.3	56.2	Phragmites australis	Abdel-Safy et al. (2009)
Kenya	MW	75.27	60.73	42.76	26.36	-	-	42.86	Cyperus papyrus	Mburu et al. (2013)
Singapore	MW	-	-	95.8	95.2	-	-	69.6	Typha angustifolia	Zhang et al. (2012)
Central America	GW	-	-	99.4	-	-	31.25	-	Cois lacryma-jobi	Dallas et al. (2004)
China	MW	-	90	70	50	-	46	60	Kandelia candel, Aegiceras corniculatum	Yang et al. (2008)
Sri Lanka	MW	65.8	65.7	40.8	74.8	38.8	-	61.2	Scirpus grossus, Hydrilla verticillata	Tanaka et al. (2003)
China	MW	86.78	86.40	76.72	-	-	44.93	81.70	Canna indica, Thalia dealbata	Shi et al. (2004)
Bangladesh	TW	55	98	98	86	50	-	87	Phragmites australis	Saeed et al. (2012)
Average removal (%)		74.37	81.20	75.87	66.47	44.4	47.87	64.50	-	-

which proveded higher transfer of oxygen to the filter medium (Kadlec and Wallace, 2008). Nitrogen removal in SSF CWs is affected by the hydraulic retention time (HRT), temperature, vegetation type and properties of the soil medium (Vymazal 2010). Although, VSSF CWs show a high potential for NH_4-N reduction due to increased transfer of oxygen by intermittent feeding, present review shows surprisingly low removal efficiencies of NH_4-N in VSSF CWs (58.23%), compare to HSSF CWs (66.47%). Furthermore, HSSF CWs show a high potential for NO_3-N reduction due to the presence of anaerobic conditions, the present review shows also low removal efficiencies

Table 3 : A summary of treatment efficiencies of vertical subsurface flow (VSSF) CWs in tropical regions

Region	WW	Removal Efficiency (%)							Plants Species	Reference
		TSS	BOD	COD	NH_4-N	NO_3-N	TN	TP		
Uganda	MW	-	-	-	75.43	60.87	72.48	83.23	Cyperus papyrus	Kyambadde et al. (2004)
Greece	MW	95	92	89	-	-	77	62	Phragmites australis	Tsihrintzis et al. (2010)
China	RW	-	-	35	71.25	-	64.85	61.24	Typha latifolia	Tang et al. (2009)
Turkey	LL	-	-	27.3	62.3	-	-	52.6	Typha latifolia	Yalcuk and Ugurlu (2009)
China	LW	-	-	40.4	45.9	62.9	51.6	51.6	Typha angustifolia	Li et al. (2008)
Beijing	RW	92.6	90.5	73.5	10.5	-	10.6	30.6	Phragmites australis, Zizania aquatica	Chen et al. (2008)
Maxico	MW	61.56	81.94	80.32	-	-	49.38	50.14	Strelitzia reginae, Anthurium andreanum	Zurita et al. (2011)
Thailand	UW	98	96	91	84	-	76	97	Scirpusgrossus Linn.	Kantawanichkul et al. (2003)
Average removal (%)		86.79	90.11	62.36	58.23	61.77	57.41	61.05	-	-

Table 4 : A summary of treatment efficiencies of hybrid system in tropical regions

Region	WW	Removal Efficiency (%)							Plants Species	Reference
		TSS	BOD	COD	NH_4-N	NO_3-N	TN	TP		
Taiwan	AW	-	-	-	86.25	97.37	95.36	31.98	Phragmites australis	Lin et al. (2002)
Indonesia	LW	-		97.72	97.21	85.96	65.66	37.33	Typha sp., Lemna sp.	Meutia et al. (2001)
Thailand	MW	90	91.58	-	-	50	68.89	46.43	Canna, Heliconia, Papyrus	Brix et al. (2011)
Turkey	MW	-	-	-	91.20	88.79	91.33	-	Iris, Phragmites australis	Tuncsiper (2009)
Spain	WNW	87.02	67.52	71.66	-	-	64.04	57.59	Phragmites australis, Juncus effusus	Serrano et al. (2011)
China	LW	99.1	77	67.4	52.8	62.25	59.4	91.8	-	Liu et al. (2007)
Maxico	MW	85.98	-	85.83	65.46	81.7	72.62	-	Phragmites communis	Belmont et al. (2004)
Columbia	MW	96.90	92.26	-	62.5	-	63.41	40	-	Arias and Brown (2009)
Average removal (%)		**91.80**	**82.09**	**80.65**	**75.90**	**70.18**	**72.55**	**50.85**	**-**	**-**

WW: Wastewater; MW: Municipal wastewater; FP: Fish pond; AR: Agricultural runoff; RW: River water; SR: Stormwater runoff; LW: Lake water; BW: Black water; GW: Greywater; TW: Tannery wastewater; LL: Landfill leachate; UW: UASB effluent; AW: Agricultural wastewater; LW: Laboratory wastewater; WNW: Winery wastewater; IW: Industrial wastewater; SW: Sugar factory wastewater of NO_3-N in HSSF (44.4%), compared to VSSF CWs (61.77%). Removal efficiencies of TN in SSF CWs generally range from 40 to 55%, and the removal level depends on the type of SSF CWs and the influent loading (Vymazal, 2007). The present review surveyed, removal efficiencies for TN in VSSF CWs were just slightly higher (57.41%) than those in (64.50%) as compared to those in VSSF CWs (61.05%).

3.3 Contaminant Removal in Hybrid System

A summary of the treatment efficiencies of hybrid systems in tropical regions is shown in Table 4. The most commonly used hybrid system is a VSSF+HSSF CW, which has been used for of both sewage and industrial wastewaters. Out of 8 of the surveyed hybrid systems, 4 were designed to treat municipal sewage, while the other hybrid systems were designed to treat various wastewaters including agricultural wastewaters, laboratory wastewater, lake water and winery wastewater. In sum, all types of hybrid systems were found to be more efficient in the removal of TSS (91.80%), BOD (82.09), COD (80.09%), NH_4-N (75.90%), NO_3-N (70.18%), TN (72.55%) and TP (50.85) compared to other types of CWs.

3.4 Overall Evaluation of Different Types of Wetland Systems

This review presents, the great potential of different types of CWs systems, to treat a broad range of wastewaters, especially in in tropical/subtropical regions, in developing countries. Fig. 2 shows the comparison of the treatment performance of the different types of CWs. In this present review, removal of BOD and TSS was very efficient and consistent, across all types of treatment wetlands. All modes of hybrid systems appeared more efficient in the removal of TSS (91.8%), NH_4-N (75.9%), NO_3-N (77.7%) and TN (72.6%), as compared to other types of CWs. VSSF CWs removed TSS (86.8%), BOD (90.1%), and 61.9% for NO_3-N, and 57.4% for TN more efficiently than HSSF CWs, while HSSF CWs showed better removal for COD (75.9%), TP (65.5%) and NH_4-N (66.5%) as compared to VSSF CWs which removed 62.4%, 61.1% and 58.2% for COD, TP and NH_4-N respectively. Compared to other types of CWs, both HSSF and VSSF CWs showed superior TP removal. VSSF systems showed the best BOD removal (9.1%) among all the CW types.

4. COST

For treatment of wastewater in any treatment system, the cost is always an important factor for consideration. In CWs systems, there have been assessed very few studies on the cost for construction, and operation and maintenance (O&M) for CW systems in developing countries.

Basic capital costs for CWs include, land, site investigation, system design, earthwork, liners, filtration media (HSSF and VSSF CWs) or rooting media (FWS CWs), vegetation, hydraulic control structures, and miscellaneous costs. Zhang et al. (2015), reviewed and reported that the capital cost (INR 11,500 to 32,250 m^{-3}) of CWs in China about 50% lesser compare to the capital cost (17,250 to 46,050 m^{-3}) of conventional wastewater treatment plant (CWWTP), and CWs usually have very low operation and maintainace (O&M) cost annually (INR 0.57 to 2.73 m^{-3}) compare to CWWTP (INR 8.06 to 17.27 m^{-3}). They reviewed another study between FWSF and VSSF CWs treating domestic wastewater in Greece, and reported the capital cost of FWSF CWs was 25,500 INR/capita and for VSSF CWs, it was 36,500 INR/capita. The O&M cost of FWSF CWs (2.7 INR m^{-3}) was lesser than VSSF CWs (9.8 INR m^{-3}). Capital costs for FWSF CWs are usually less than SSF CWs systems mainly due to cost for media is limited to rooting soil on the bottom of beds. Althouhg, In India, it was reported that the capital cost of SSF CWs was 5,450 INR m^{-3} and O&M cost was 0.6 INR m^{-3} (CSE, 2015)

5. CONCLUSIONS

To fulfil the provision under economically and environmentally sustainable approach, to control water pollution, CWs have been implemented successfully as green and cost-effective technology to solve the problems of broad range of wastewters in many tropical and subtropical regions of developing countries. Although, there are accordingly very lesser published reports on application of CWs under tropical environment. Therefore, the emphasis of this review has been on the treatment performance of various types of CWs including FWSF, HSSF and VSSF CWs, and hybrid system in tropical countries. This review presented the use of CWs has great potential in treatment of various wastewaters, especially in tropical region in developing countries.

REFERENCES

Arias, M.E. and Brown, M.T. (2009) Feasibility of using constructed wetlands for municipal wastewater treatment in the Bogotá Savannah, Colombia. *Ecol. Eng.,* 35, pp. 1070-1078.

Bavor, H.J., Roser, D.J., McKersie, S.A. and Breen, P. (1988) Treatment of secondary effluent. A report of Sydney Water Board, Australia.

Belmont, M.A., Cantellano, E., Thompson, S., Williamson, M., Sánchez, A. and Metcalfe, C.D. (2004) Treatment of domestic wastewater in a pilot-scale natural treatment system in central Mexico. *Ecol. Eng.*, 23, pp. 299-311.

Brix, H. and Schierup, H. (1990). Soil oxygeneration in constructed reed beds: The role of macrophyte and soil atmosphere interface oxygen transport. In Constructed wetlands in water pollution control (pp. 53–66). Oxford, UK: Pergamon Press.

Brix, H., Koottatep, T., Fryd, O. and Laugesen, C.H. (2011) The flower and the butterfly constructed wetland system at Koh Phi Phi-System design and lessons learned during implementation and operation. *Ecol. Eng.*, 37(5): pp. 729-735.

Chaturvedi, M. K. M., Langote, S. D., Kumar, D. and Asolekar, S. R. (2014) Significance and estimation of oxygen mass transfer coefficient in simulated waste stabilization pond. *Ecol. Eng.*, 73, pp. 331-334.

Chen, Z.M., Chen, B., Zhou, J.B., Li, Z. and Zhou, Y. (2008) A vertical subsurface-flow constructed wetland in Beijing. Commun. *Nonlinear Sci. Numer. Simul,.* 13, pp. 1986-1997.

CPCB (2016) Central Pollution Control Board, Bulletin (2016) Vol I.

CSE (2015) Centre for Science and Environment. https://www.cseindia.org/constructed-wetland-for-wastewater-treatment-at-indian-agriculture-research-institute-pusa-new-delhi-5632

Dallas, S., Scheffe, B., and Ho, G. (2004) Reedbeds for greywater treatment e case study in Santa Elena-Monteverde, Costa Rica, Central America. *Ecol. Eng.*, 23, pp. 55-61.

Dan, T.H., Quang, L.N., Chiem, N.H. and Brix, H. (2011) Treatment of high-strength wastewater in tropical constructed wetlands planted with *Sesbania sesban*: horizontal subsurface flow versus vertical downflow. *Ecol. Eng.* 37 (5): pp. 711-720.

Haandel, A. and Lubbe, J. (2007) Handbook biological waste water treatment. The Netherlands: Quist Publishing.

Jinadasa, K.B.S.N., Tanaka, N., Mowjood, M.I.M. and Werellagama, D.R.I.B. (2006) Free water surface constructed wetlands for domestic wastewater treatment: a tropical case study. *J. Chem. Ecol.* 22(3): pp. 181-191.

Kadlec, R. H. and Wallace, S. D. (2009) Treatment wetlands (1st ed.). Boca Raton, FL: CRC Press Taylor and Francis Group.

Kadlec, R.H. and Knight, R.L. (1996) Treatment Wetlands. CRC Press Inc., Boca Raton, FL.

Kadlec, R.H. and Wallace, S. (2008) Treatment Wetlands. 2nd ed. CRC Press, Boca Raton, FL.

Kantawanichkul, S., Somprasert, S., Aekasin, U. and Shutes, R.B.E. (2003) Treatment of agricultural wastewater in two experimental combined constructed wetland systems in a tropical climate. *Water Sci. Technol.,* 48(5): pp. 199-205.

Kumar, D., Asolekar, S. R., Sharma, S. K. (2015) Post-treatment and reuse of secondary effluents using natural treatment systems: The Indian practices. *Environ. Monit. Assess.* 187: 612.

Kyambadde, J., Kansiime, F., Gumaelius, L. and Dalhammar, G. (2004) A comparative study of Cyperus papyrus and Miscanthidium violaceum-based constructed wetlands for wastewater treatment in a tropical climate. *Water Res.,* 38, pp. 475-485.

Li, L., Li, Y., Biswas, D.K., Nian, Y., Jiang, G. (2008) Potential of constructed wetlands in treating the eutrophic water: evidence from Taihu Lake of China. *Bioresour. Technol.*, 99, pp. 1656-1663.

Lin, Y.F., Jing, S.R., Lee, D.Y. and Wang, T.W. (2002) Nutrient removal from aquaculture wastewater using a constructed wetlands system. *Aquaculture*, 20(1-4): pp. 169–184.

Liu, C., Du, G., Huang, B., Meng, Q., Li, H., Wang, Z. and Song, F. (2007) Biodiversity and water quality variations in constructed wetland system. *Acta Ecol. Sin.,* 27(9): pp. 3670-3677.

Masi, F., Martinuzzi, N. (2007) Constructed wetlands for the Mediterranean countries: Hybrid systems for water reuse and sustainable sanitation. *Desalination,* 215(1-3): pp. 44-55. 10.1016/j.desal.2006.11.014

Mburu, N., Tebitendwa, S.M., Rousseau, D.P.L., van Bruggen, J.J.A. and Lens, P.N.L. (2013) Performance evaluation of horizontal subsurface flow-constructed wetlands for the treatment of domestic wastewater in the tropics. *J. Environ. Eng.*, 139, pp. 358-367.

Meutia, A.A. (2001) Treatment of laboratory wastewater in a tropical constructed wetland comparing surface and subsurface flow. *Water Sci. Technol.*, 44(11-12): pp. 499-506.

Saeed, T. and Sun, G. (2012) A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: Dependency on environmental parameters, operating conditions and supporting media. *J. Environ. Manage.*, 112, pp. 429-448.

Saeed, T. and Sun, G. (2017) A comprehensive review on nutrients and organics removal from different wastewaters employing subsurface flow constructed wetlands. *Critical Reviews in Environmental Science and Technology*, 47(4): pp. 203-288. https://doi.org/10.1080/10643389.2017.1318615

Saeed, T., Afrin, R., Muyeed, A.A. and Sun, G. (2012) Treatment of tannery wastewater in a pilot-scale hybrid constructed wetland system in Bangladesh. *Chemosphere*, 88, pp. 1065-1073.

Serrano, L., de la Varga, D., Ruiz, I. and Soto, M. (2011) Winery wastewater treatment in a hybrid constructed wetland. *Ecol. Eng.*, 37(5): pp. 744-753.

Shi, L.,Wang, B., Cao, X.,Wang, J., Lei, Zhi,Wang, Z., Liu, Z. and Lu, B. (2004) Performance of a subsurface-flow constructed wetland in Southern China. *J. Environ. Sci.*, 16(3): pp. 476-481.

Sim, C.H., Yusoff, M.K., Shutes, B., Ho, S.C. and Mansor, M. (2008) Nutrient removal in a pilot and full scale constructed wetland, Putrajaya city, Malaysia. *J. Environ. Manage.*, 88, pp. 307-317.

Tanaka, N., Jinadasa, K.B.S.N.,Werellagama, D.R.I.B., Mowjood, M.I.M. and Ng,W.J. (2013) Constructed tropical wetlands with integrated submergent-emergent plants for sustainable water quality management. *J. Environ. Sci. Health A*, 41, pp. 2221-2236.

Tang, X.Q., Huang, S.L. and Scholz, M. (2009) Nutrient removal in pilot-scale constructed wetlands treating eutrophic river water: assessment of plants, intermittent artificial aeration and polyhedron hollow polypropylene balls. *Water Air Soil Pollut.*, 197, pp. 61-73.

Tsihrintzis, V.A., Akratos, C.S., Gikas, C.D., Karamouzis, D. and Angelakis, A.N. (2010) Performance and cost comparison of a FWS and a VSF constructed wetland system. *Environ. Technol.*, 28(6): pp. 621-628.

Tunçsiper, B. (2009) Nitrogen removal in a combined vertical and horizontal subsurface-flow constructed wetland system. *Desalination*, 247(1-3): pp. 466-475.

UN Water (2008) Tackling a Global Crisis: International Year of Sanitation 2008. http://www.wsscc.org/fileadmin/files/pdf/publication/IYS_2008__tackling_a_global_crisis.pdf

Vymazal, J. (2005) Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. *Ecol. Eng.* 25(5): pp. 478-490.

Vymazal, J. (2007) Removal of nutrients in various types of constructed wetlands. *Sci. Total Environ.*, 380(1-3): pp. 48-65.

Vymazal, J. (2010) Constructed Wetlands for Wastewater Treatment. *Water*, 2, pp. 530-549. doi:10.3390/w2030530

Wang, M., Zhang, D., Dong, J. and Tan, S.K. (2018). Application of constructed wetlands for treating gricultural runoff and agro-industrial wastewater: a review. *Hydrobiologia*, 805, 1–31.

Wen, L., Hua, C.L., Ping, Z.Y. and Xiang, L.Z. (2011) Removal of total phosphorus from septic tank effluent by the hybrid constructed wetland system. *Procedia environmental sciences,* 10, pp. 2102-2107.

Wu, H., Lin, L., Zhang, J., Guo, W., Liang, S. and Liu, H. (2016) Purification ability and carbon dioxide flux from surface flow constructed wetlands treating sewage treatment plant effluent. *Bioresour. Technol.*, 219, pp. 768-772

Yalcuk, A. and Ugurlu, A. (2009) Comparison of horizontal and vertical constructed wetland systems for landfill leachate treatment. *Bioresour. Technol.*, 100(9): pp. 2521-2526.

Yang, Z.F., Zheng, S.K., Chen, J.J. and Sun, M. (2008). Purification of nitrate-rich agricultural runoff by a hydroponic system. *Bioresour. Technol.,* 99, pp. 8049-8053.

Zhang, D.Q., Jinadasa, K.B.S.N., Gersberg, R.M., Liu, Y., Tan, S.K. and Ng, W.J. (2015) Application of constructed wetlands for wastewater treatment in tropical and subtropical regions (2000–2013). *Journal of Environmental Scence*. http://dx.doi.org/10.1016/j.jes.2014.10.013

Zhang, D.Q., Tan, S.K., Gersberg, R.M., Sadreddini, S., Zhu, J.F. and Nguyen, A.T. (2011) Removal of pharmaceutical compounds in tropical constructed wetlands. *Ecol. Eng.* 37(3): pp. 460–464.

Zhang, D.Q., Tan, S.K., Gersberg, R.M., Zhu, J.F., Sadreddini, S. and Li, Y.F. (2012) Nutrient removal in tropical subsurface flow constructed wetlands under batch and continuous flow conditions. *J. Environ. Manag.* 96 (1): pp. 1-6.

Zurita, F., Belmont, M.A., De Anda, J. and White, J.R. (2011) Seeking a way to promote the use of constructed wetlands for domestic wastewater treatment in developing countries. *Water Sci. Technol.*, 63(4): pp. 654-659.

Long Term Management Plan for Pollutant Mass Reduction by Variable Withdrawal Rates in a Confined Aquifer

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ABSTRACT

Groundwater, extracted from aquifers which are the deep geological formation through pumping wells, forms a vital component of many water resource systems. Pollution of groundwater has become a major problem for its safe utilization. The flow of groundwater pollutants in an aquifer depends upon boundary conditions, initial conditions, hydro geological information and wells. Deep rooted planning of groundwater usage requires a well decision support tools which are based on analysis. The main requirement of such tools is that they are to be able to forecast the change in the groundwater storage with adequate precision, and must permit exploring management scenarios. The temporal and spatial distribution of pollutants from different fields can be studied by 2-D and 3-D groundwater modeling. A groundwater model gives a quantitative structure for amalgam of field information and for conceptualizing hydro geologic process. A concentration response matrix was obtained by using the analytical simulation model.The concentration over time gets computed by model which is due to the processes like hydrodynamic dispersion, convective transport and fluid sources dilution.This study aims to analyze the plume behaviour with variation in pumping well discharge. The flow and transport simulation model MOC (USGS) is used for getting different response data sets of pollution concentration realization at pollutant monitoring locations of the study area. The pollutant concentration values at each node of the study area are found for a management period of 5 years and various cases along with scenarios are developed to find out best management plan for pumping schedule.

Keywords *: Groundwater, Pollute Transport, Method of Characteristics, 2-D Groundwater Modeling, Kriging.*

1. INTRODUCTION

Groundwater is considered as extremely reliable and safe source of water supply for agriculture, domestic, commercial and industrial needs. Use of chemical fertilizers in high quantity together with improper water management practices has resulted in the worsening of groundwater quality. Pollutant such as metals, pesticides, chlorinated solvents and other abandoned or buried chemicals are dissolved in and spread with the water and the preferred pathways used by water for its transport mostly, cannot be accessed easily which makes the modeling more difficult. Computer models for understanding and predicting hydraulics and pollutant transport in aquifers make assumptions about the distribution and hydraulic properties of geologic features. The water content in the geologic formation varies with the depth below ground surface. Groundwater modeling aims at studying the temporal and spatial distribution of such pollutants in the aquifer and thus formulates sustainable groundwater strategies. It is basically a tool to project the state variables of the groundwater system for an assigned pattern of forcing function and initial and boundary conditions and parameters. In last few decades, optimal monitoring network design problem under condition of uncertainty has been taken into the account by the number of researchers. Cieniawski et al. (1995) presented their method based on the work of Meyer and Brill (1988) on the optimal location of a network of groundwater monitoring wells under conditions of uncertainty. Jha et al. (2000) used LP technique to determine the areal distribution of groundwater pumping which can provide the maximum amount of pumping within the permissible critical groundwater level during dry periods. Banks and Dillow (2001) was developed simulation-optimization model and provided an optimal solution for flow system and amount of water needed to maintain capture. Dhar and Dutta (2007) given a solution of optimization models for optimal design of groundwater quality monitoring networks and gave results for the possible application of the projected models for scheming a cost-effective groundwater contamination monitoring network. Safaan et al. (2011) given MOGA model forthe highest pumping rate and lowest amount operation cost as well as the forecast of the future changes in both pumping rate and pumping operation cost. Singh and Datta (2016) utilizes a Kriging-linked SA-based optimization model and numerical flow and transport simulation model (MODFLOW and MT3DMS) is used to simulate the processes (Physical and Geochemical) for design of an optimal groundwater pollution monitoring system for various flow and transport scenarios. Gangwar and Singh (2017) suggested a model to design an optimal dynamic groundwater monitoring network for aquifer with varying thickness to determine the mass estimation error of pollutant concentration at different time intervals.

The paper presents a methodology to obtain the pollutant mass collected over the entire aquifer with variation in pumping rates over the management period and to determine the optimal pumping rates for minimizing the total pollutant mass in the study area.

2. METHODOLOGY

The equation describes the transient, two-dimensional areal flow of groundwater through a non-homogeneous, anisotropic, saturated aquifer can be written in Cartesian tensor notation (Pinder and Bredehoeft, 1968) as:

$$\frac{\partial}{\partial x_i}\left(T_{ij}\frac{\partial h}{\partial x_j}\right) = S\frac{\partial h}{\partial t} + W; \qquad i, j = 1,2 \qquad ...(1)$$

Where, T_{ij} is the transmissivity tensor (L^2T^{-1}) = K_{ij} b, K_{ij} is hydraulic conductivity tensor (LT^{-1}), b is saturated thickness of aquifer (L), h is the hydraulic head (L), W is volume flux per unit area (LT^{-1}) and x_i, x_j are cartesian coordinates (L). In the present study, the flow model is simulated using MOC.

2.1 Method of Characteristics

The Method of Characteristics (MOC, USGS) is used in this model to solve the solute-transport equation. The method was developed to solve hyperbolic differential equations.

$$\frac{\partial C}{\partial t} = \frac{1}{b}\frac{\partial}{\partial x_i}\left(\mathrm{b}\, D_{ij}\frac{\partial C}{\partial x_j} - V_i\frac{\partial C}{\partial x_i} + \frac{C\left(S\frac{\partial h}{\partial t} + W - \varepsilon\frac{\partial b}{\partial t} - C'W\right)}{\epsilon b}\right) \qquad ...(2)$$

Equation (2) is the form of the solute transport equation that is solved in the computer program.

2.2 Pollutant Transport Equations

The partial differential equation describes the fate and transport of pollutants of species *k* in 3-D, transient groundwater flow systems can be written as follows (MT3DMS, 1999):

$$\frac{\partial(\theta C^k)}{\partial t} = \frac{\partial}{\partial x_j}\left(\theta D_{ij}\frac{\partial C^k}{\partial x_j}\right) - \frac{\partial}{\partial x_i}\left(\theta v_i C^k\right) + q_s C_s^k + \Sigma R_n \qquad ...(3)$$

Where, θ is dimensionless subsurface medium porosity, C^k is the dissolved concentration of species k, ML^{-3}, t is time, T, $x_{i,j}$ is the distance of the respective Cartesian coordinate axis, L and D is hydrodynamic dispersion coefficient tensor, L^2T^{-1}, is seepage or linear pore water velocity, LT^{-1}; it is related to the specific discharge or Darcy flux through the relationship, $v_i = q_i/\theta$; q_i is the volumetric flow rate per unit volume of aquifer representing fluid sources and sinks, T_{-1}, C^4, is concentration of the source or sink flux for species k, M_{L-3} and ΣR_n is the chemical reaction term, $ML^{-3}T^{-1}$.

2.3 Initial Conditions

The initial conditions are important for the simulation model to give solution of the governing groundwater equation which describes temporary changes in solute concentration with respect to time. These conditions are given as:

$$H(x, y, z, t) = h\_0(x, y, z) \quad \text{on}\Omega; \quad t = 0 \qquad ...(4)$$

$$C(x, y, z, t) = c\_0 (x, y, z) \quad \text{on}\Omega; \quad t = 0 \qquad ...(5)$$

Where c_0(x, y, z) and h_0(x, y, z) is a known concentration and head distribution and Ω denotes the entire model domain.

2.4 Boundary Condition

General boundary conditions are taken as:

$$C(x, y, z, t) = c (x, y, z, t) \text{ on } \Gamma_1; \; t \geq 0 \qquad ...(6)$$

$$H(x, y, z, t) = h (x, y, z, t) \text{ on } \Gamma_2; \; t \geq 0 \qquad ...(7)$$

Where : Γ_1 and Γ_2 = specified concentration/head boundary, c (x, y, z, t) and h(x, y, z, t) = specified concentration/head along Γ_1 and Γ_2.

3. MODELING AND SOFTWARE

Groundwater flow and transport model MOC (USGS) is used to predict the water table fluctuations and pollutant concentration values at various nodes under varying pumping and recharge rates.

3.1 Modeling Steps

The two-dimensional models of a hypothetical confined aquifer.The study area is discretized into a block centered finite difference grid having 10 rows and 10 columns covering 11,38,062.24 square meter. A pumping wells are taken as withdrawal (discharge) wells. The model assumes that stresses developed in the aquifer are independent of time during each pumping phase. The source concentration rate their location and pumping well locations are unchged during the management period. The model produces the head and concentration of pollutant at ten observation wells on specified locations (as shown in Fig. 1). Other parameters like constatnt head boundaries, pollutant source, no flow boundaries, transmissivity, etc. can be put in as node detection arrays. The various steps include the following:

(i) The study area was discritized into a block centered finite difference grid.

(ii) The number of nodes in both directions (x and y) were taken as ten. The breadth of the finite difference cell in both x and y directions are equal and came out to be 106.68 m (350 feet).

(iii) The finite difference grid uses maximum number of particles upto a limit of 3200, and the initial number of particles per node was set to 9.

(iv) Potential locations in the study area were utilized to locate the 5 observation wells.

(v) The locations of the 4 variable pumping wells were also specified along with their variable rate of discharge.

(vi) A no-flow boundary was established around the area of study.

(vii) A node recognition array was defined to visibly separate the constant head boundaries, no flow boundaries and pollutant source in the grid.

(viii) Position of the water table was identified on the grid. The potentiometric heads in the water table were assumed as 148 m, 146 m. The initial concentration of the hypothetical contaminated source was assumed as 300 mg/l.

(ix) A input file was generated detailing the aquifer properties, initial conditions and boundary conditrions.

(x) Various cases alongwith scenarios were developed and contaminat concentration was obtained at all the grid nodes with varying pumping discharges.

(xi) Extrapolation method, kriging, was used to estimate the concentration over the entire aquifer area and calculate the total pollutant mass.

3.2 Application

Spatial Discretization

The area under the study is hypothetical. As required by the model, the whole area was enclosed in a rectangular area. The rectangle is itself 10×10 grid is 106.68 m in both x and y directions with each cell having size of 106.68 m in both directions (x and y). The top left corner was considered as the point of origin as prescribed by the model. The area concerned was the confined aquifer with variable thickness, variable hydraulic conductivity, and variable pumping well rate. The area concerned has been shown in Fig. 1.

Fig. 1. Shows 10×10 grid drawn on the area, showing the locations of no-flow boundary (orange), constant – head boundary (yellow), pumping wells P1, P2, P3, P4 (green), observation wells O1, O2, O3, O4, O5 (blue) and S1, S2 are the pollution source (brown). Apart from the above-stated inputs, several other required inputs about the hydro-geological characteristics of the aquifer were also needed for simulation of groundwater flow and transport model are shown in Table 1.

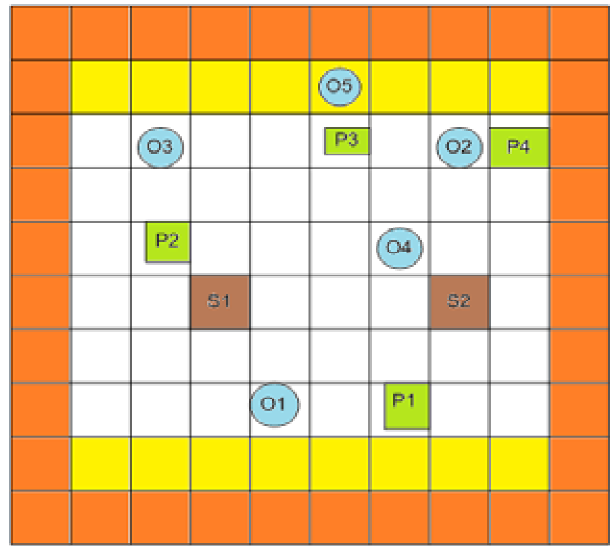

Fig. 1 : 10×10 grid drawn on the area, showing locations

Table 1 : Input for Hydro-geological characteristics of model

Parameter	Input Value
Thickness of Aquifer	6.096 m
Transmissivity	0.0185 m²/sec
Longitudinal Dispersivity	30.48 m
Transverse Dispersivity	9.144 m
Water Table Head	45.11 m in the upward region and 44.51 m in the south corner region
Storage Co-efficient	0
Pumping Period	5 years

3.3 Parameters Used in the Model

The variables set for a contoured imitation process used in model are provided in Table 2.

Table 2 : Model Variables or Parameters

Parameters	Value
Pumping period time steps	50
Pumping Periods number	1
Entire Pumping Periods	5 years
X-direction nodes	10
Breadth of finite-difference cell in x-direction	106.68 m
Y-direction nodes	10
Width of finite differences cell in y-direction	106.68 m
Upper limit of particles	3200
Initial number of particles per node	9
Number of node identification codes	2
Maximum cell distance per particle move	0.50
Meeting criterion (converge)	0.0001

4. RESULTS AND ANALYSIS

In the above study discussion for different cases for variable pumping rates has been done. Fig. 2 shows least obtained values for total pollutant mass under every case.

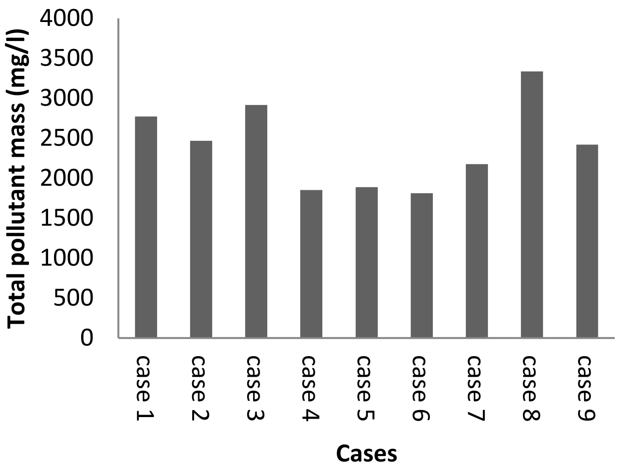

Fig. 2 : Plot showing variation in pollutant mass under different cases

Table 3 : Pollutant mass under different cases

Case	Total Pollutant Mass (mg/L)
1	2772
2	2466
3	2915
4	1852
5	1888
6	1809
7	2175
8	3335
9	2419

4.1 Estimation of Pumping Wells

Based on the actual field practices adopted by water supply agencies the variation in the pumping rates were determined and upper limit of the pumping rate was keptat 0.047 m^3/s and lower limit as 0.021 m^3/s. The scenarios generated during all the nine cases under different conditions are given in Table 4.

From Fig. 1, which represents the results of concentration values when two wells are in working condition at maximum pumping rate and other two wells are in non-working condition, the least optimal value of total pollutant mass by comparing all the cases was in case 6, i.e., 1809 mg/l.

Table 4 : Scenarios generated during different pumping conditions

Case	Pumping Wells Condition
1	When 1 well is at maximum pumping rate and others are in non-working condition (4 scenarios generated)
2	When one well is at minimum pumping rate and others are in non-working condition (4 scenarios generated)
3	When at one time all the wells are running with minimum variable rate and one time at minimum variable rate. (2 scenarios generated)
4	When one pumping well is at maximum pumping rate and one pumping well is at minimum pumping rate and other two are in non-working condition. (12 scenarios generated)
5	When two wells are in working condition at minimum pumping rate and other two wells are in non-working condition (6 scenarios generated)
6	When two well are in working condition at maximum pumping rate and other two wells are in non-working condition (6 scenarios generated)
7	When three well are in working condition at minimum pumping rate and one well is in non-working condition (4 scenarios generated)
8	When three well are in working condition at maximum pumping rate and one well is in non-working condition (4 scenarios generated)
9	When all the four pumping wells are working atdifferent variable rate. (60 scenarios generated)

CONCLUSIONS

In the present study for minimizing the total mass of pollutant in the aquifer was computed with the variable pumping rates. The change in pumping rate was based on discrete input method. This work can be extended further by linking the pumping rate variation with groundwater simulation model and ultimately the Scenario should be linked to any optimization model which by iteration can give us the global optimal results for the best pumping rate combination among the four pumping wells. The model predicts the spread of pollutant mass transport for a time period of 5 years and the headlevels at the end of the time period. The simulation results indicate that the pumping also affects the fast movement of pollutant plume. The

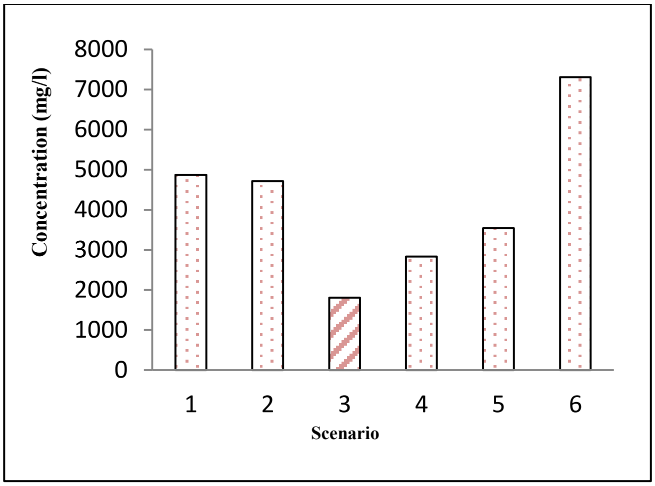

Fig. 3 : Plot representing the case 6 for concentration values when two well are in working conditionat maximum pumping rate and other two wells are in non-working condition.

direction of the plume movement can be predicted and controlled by the long term management. The policy regarding the optimal operation of the pumping wells will lead to a better management between the administration and the public to have safe utilization of groundwater.

REFERENCES

Bear, J. and Cheng, A.H.D., (2010). Modeling Groundwater Flow and Pollutant Transport, In Theory and Application of Transport in Porous Media, (ISBN No. 978-1-4020-6681-8), vol. 23, Springer, p. 834.

Cieniawski, S.E., Eheart, J.W. and Ranjithan, S. (1995). Using genetic algorithms to solve a multi objective groundwater monitoring problem. Water Resour. Res., Vol. 31(2), p. 399-00.049.

Dhar, A. and Datta, B. (2007). Multiobjective design of dynamic monitoring networks for detection of groundwater pollution. Jl. of Water Resources Plng. and Mgmt., ASCE, 133(4), 0.0329-30.038.

Gangwar, S. and Singh, D. (2017). Dynamic Groundwater Monitoring Network Design for Aquifers with Varying Thickness.Proceedings of Recent Trends in Civil Engineering and Water Resource Engineering, (RTCWRE-17), (ISBN No. 978-93-86256-99-7), 2017.

Saffan, T.A., Moharram, S.H. and Khalafallah, S. (2011). International Journal of Water Resources and Environmental Engineering Vol. 3(7), pp. 139-149, August 2011.

Singh, D., Datta, B. (2014). Optimal Groundwater Monitoring Network Design for Pollution Plume Estimation with Active Sources, International Journal of GEOMATE, Vol. 6, No. 2, Japan.

Singh, D. (2015). Groundwater Monitoring Network Design: An Optimal Approach, L.A. Publishing, Deutschland, Germany.

Banks, S.L. William and Dillow, J.A. Jonathan, (2001). Optimization of Ground-water Withdrawal at the Old O-field Area, Aberdeen Proving Ground, Maryland, Water Resource Investigation Report, U.S. Army Garrison, Maryland.

Konikow, L.F. and Bredehoeft, J.D. (1984).Computer Model of Two-Dimensional Solute Transport and Dispersion in Groundwater.Techniques of Water Resource Survey, Chapter 2, U.S. Government Printing, Washington.

Artificial Intelligence (AI) - Based Reverse Osmosis Water Desalination Models

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ABSTRACT

Desalination of brackish water and seawater are the main sources of many countries which afflict rainwater scarcity and are deprived of lakes and rivers. There are several methods for desalination of water such as membrane distillation, solar evaporation, electrodialysis reversal, multi-stage flash distillation, reverse osmosis, etc. Reverse osmosis is more popular because of its simple design and economic factors such as require low energy, minimal operating temperature, and low water production costs. In the current study, artificial intelligence (AI)-based reverse osmosis water desalination models have been developed using AI techniques viz. artificial neural networks (ANN) and support vector regression (SVR). The input parameters of the models include sodium chloride concentration, feed temperature and pressure. The permeate rate is used as the output parameter. The developed AI-based models are evaluated and validated against the reported experimental data present in the literature. These AI-based models are then further compared with the widely used multiple linear regression (MLR) over the virgin test (unseen) dataset based on statistical measures like average absolute relative error (AARE), coefficient of determination (R^2), etc. The SVR-based model exhibits a low value of AARE of 1.95% and a value of high R^2 of 0.9963 while the corresponding values for ANN and MLR models are 9.35%, 52.04%, 0.9899 and 0.9157, respectively. Thus, the structural risk minimization (SRM) principle based SVR model is found to be the best, more accurate and generalized in comparison to the empirical risk minimization (ERM) based MLR and ANN models for the permeate rate prediction. Furthermore, through these AI techniques, excellent predictions can be made for the unseen data which not only reduces the number of experiments to be done but also helps the more effective design and fabrication of membrane-based desalination unit.

Keywords *: Reverse osmosis; SVR; ANN; R^2; AARE.*

1. INTRODUCTION

Seawater and brackish water are considered to be the main source of water in most of the countries which incur from rainwater and lack rivers and lakes. Various desalination technologies are used for the removal of excess salts and mineral from water into potable water. Desalination technology is broadly classified into thermal and membrane desalination technology. Thermal desalination technology contains vapor compression evaporation, multi-stage flash distillation, cogeneration, multi-effect distillation, and solar water desalination while membrane desalination technology comprises of electrodialysis, reverse osmosis and membrane distillation. Reverse osmosis (RO) is found to be an effective and economical method for the treatment of sea and brackish water. In a typical RO process, salty water flows through a semipermeable membrane under pressure as the driving force. Pure water passes through the membrane and the more concentrated salt is left behind. Seawater RO plant recovers around 20 to 40% of the feed water accompanying 90 to 98% salt rejection. For brackish water RO plants, recovery rates vary from 50 to 80% of the feed water accompanying 90 to 98% salt rejection.

Artificial neural networks (ANN) has been utilizing in the past for the desalination process (Khayet et al., 2011; Salgado-Reyna et al., 2015). But, recently, support vector regression (SVR) has appeared as an excellent artificial intelligence (AI) technique offering many advantages over the conventional neural network (ANN) and other regression technique such as optimal, global and unique solution for the convex optimization problem, kernel parameter and upper bound are only the two parameters that is required. Furthermore, structural risk minimization (SRM) principle of SVR offers excellent generalizability.

In this research paper, AI-based models viz. SVR and ANN models is well developed to predict the permeate rate for reverse osmosis water desalination unit. The developed models are then compared with the widely utilized multiple linear regression (MLR) model.

2. SUPPORT VECTOR REGRESSION (SVR)

Support vector machines (SVMs) application is not limited to classification but also, has been extended to regression (Gunn, 1997; Parveen et al., 2017; Smola and Schölkopf, 2004). Training dataset for a given regression problem as: P = {(r_1, s_1), (r_2, s_2),…, (r_i, s_i),…. (r_N, s_N)}, such that $r_i \epsilon R^N$ and $s_i \epsilon R_N$ are the vectors of independent input and dependent target variables.

The regression function in high dimensional feature space is expressed below:

$$f(r,w) = (w \bullet \phi(r) + z) \quad ...(1)$$

Where, w, z, $\phi(r)$ and $w \bullet \phi(r)$ are weight vector, constant, feature function and the dot product.

The above regression is minimized as given below:

$$\text{Minimize: } R(f) = C\frac{1}{N}L_\varepsilon(s, f(r,w)) + \frac{1}{2}||w^2|| \quad ...(2)$$

$$L_\varepsilon(s, f(r,w)) = \begin{cases} 0 & if|\boldsymbol{s} - f(r,w) \le \varepsilon \\ |\boldsymbol{s} - f(\boldsymbol{r},w)| - \varepsilon & otherwise \end{cases} \quad ...(3)$$

In Eq. (2), former term and the latter term denotes the empirical error and model flatness while term C represents the optimize value between these two terms. Eq. (3) is used to define ε- insensitive loss function by Vapnik et al. (1996). Lagrangian multiplier λ and λ* is employed to convert the above optimization problem into the dual problem. The input vectors, r_i, having non-zero coefficients are termed as support vectors (SVs). In the end, SVR expression is obtained using kernel function $K(r_i, r_j)$ as given below in Eq. (4):

$$f(\boldsymbol{r}, \lambda_i, \lambda_i^*) = \sum_{i=1}^{N_{sv}}(\lambda_i - \lambda_i^*)\, K(\boldsymbol{r}, \boldsymbol{r_i}) + z \quad ...(4)$$

$$\text{Where } K(\boldsymbol{r}, \boldsymbol{r_i}) = \left(\emptyset(\boldsymbol{r_i}) \bullet \emptyset(\boldsymbol{r_j})\right)$$

The term, z, can be acquired employing the Karush–Kuhn–Tucker (KKT) conditions.

2.1 Procedure for the Development of the SVR Model

The computational means of SVR modelling can be found in the open literature (Cherkassky and Ma, 2004; Lee and Chern, 2013; Shi et al., 2012). The various steps involved in SVR modeling is well described in Fig. 1. Firstly, the data is collected in the form of independent input and dependent output variables. Afterward normalizing the entire dataset to avoid the influence of larger data on to a smaller data by making it in a suitable range. And then the normalized dataset is breakup into the training set and test (unseen) set. The next step holds the optimization of the parameters of model (C, ε, RBF kernel γ) employing a grid search technique with 10-fold cross-validation. Finally, the obtained optimal parameters are utilized to build the SVR model. Further, evaluating and validating the SVR model performance in terms of various statistical measures.

3. ARTIFICIAL NEURAL NETWORKS (ANN)

Artificial neural networks (ANN) is a parallel information processing system i.e. information is distributed over each and every node rather than being held at fixed one location. The processing of ANN depends on network topology, weights or learning, and the type of activation used. These are also called as the building block of ANN. ANN comprises of the input layer, the hidden layers, and the output layers. Sometimes neural networks is commonly known as universal approximator since it can approximate any continuous function to the required degree of accuracy by using a large number of hidden neurons. Use of too many or too few neurons might render the problem of over-fitting or under-fitting (Panchal and Panchal, 2014).

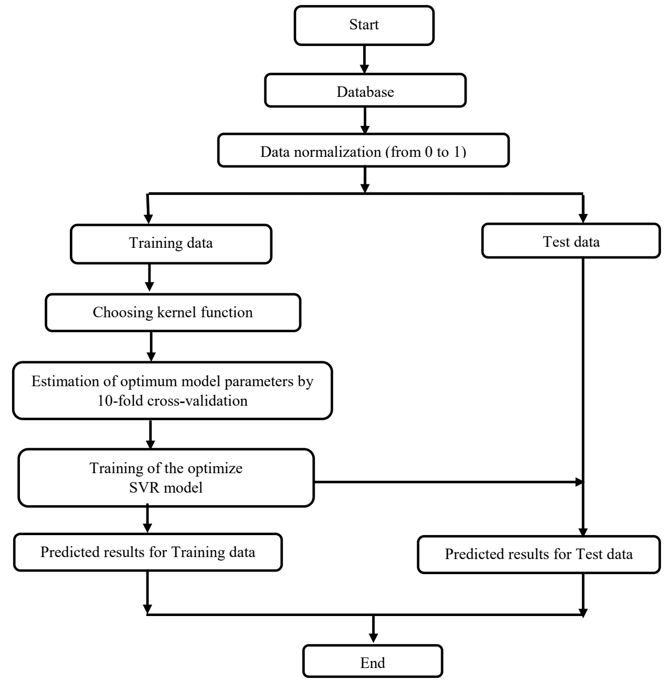

Fig. 1 : SVR modeling procedure

3.1 Procedure for the Development of ANN Model

The basic steps required for developing the ANN model can be explained with the help of a flowchart as shown in Fig. 2 (Devabhaktuni et al., 2001; Madić and Miroslav, 2011; Musharavati and Hamouda, 2010). Firstly, the data is collected in the form of the independent and dependent variable of the particular problem and then preprocessing the entire dataset (normalizing or scaling the data and removal of outliers is also required sometimes). Partitioning the entire dataset into three sets as training, testing and validation set. Next step is creating ANN architecture i.e. no. of neuron at the input layer, the hidden layers and the output layers, the form of ANN, no. of hidden layers, the hidden layer, and the output layer transfer function are specified. After finalizing the network architecture, neural networks training is done: (a) weight and bias are adjusted using training set, (b) the generalization performance checked via validation set and post training analysis to stop the training process and (c) the predictability of the ANN model is analyzed with the test set based on some statistical measures. Finally, the trained network can be utilized for prediction.

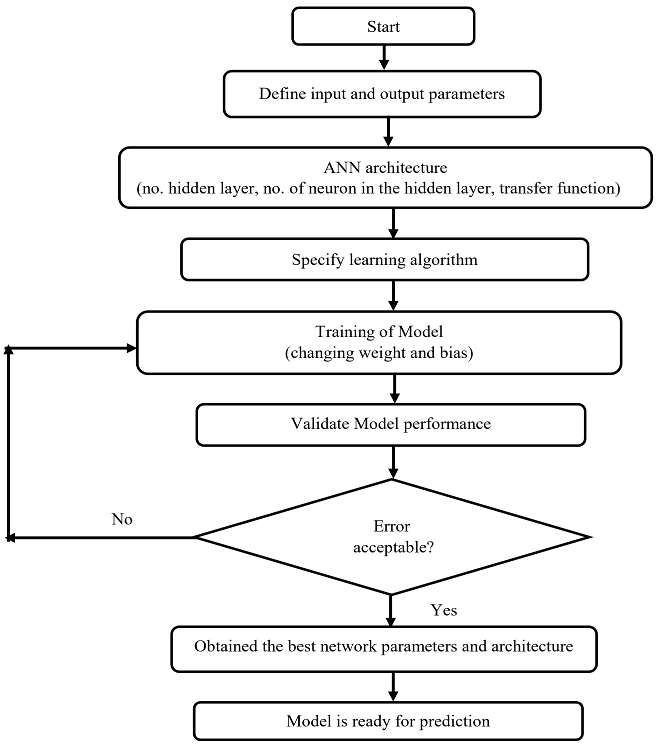

Fig. 2 : ANN modeling procedure

4. RESULTS AND DISCUSSION

In this work, the most popular soft computing techniques viz. SVR and ANN have been applied for predicting permeate rate (y) with the input parameters: pressure of the feed (x_1), feed temperature (x_2), and concentration of sodium chloride (x_3). The entire dataset of 63 data points obtained from the literature (Abbas and Al-bastaki, 2005) is randomly split into 80% as the training set (50 data points) and 20% as the test set (13 data points) respectively. LIBSVM package (Chang and Lin, 2001) and ANN toolbox in MATLAB platform is employed to develop the SVR and the ANN models. Comparative analysis of the develop models with the empirical results is done based on statistical measures like mean relative error (MRE), average absolute relative error (AARE), standard deviation (SD), coefficient of determination (R^2), root mean square error (RMSE), leave-one-out cross-validation for training set (Q^2_{LOO}) and leave-one-out cross-validation for test set (Q^2_{ext}).

4.1 Analysis of SVR-based Model

RBF kernel is chosen amongst several kernel functions viz. linear, polynomial, radial basis function (RBF), and sigmoid kernel because of its fair generalizability and needs only one parameter to be specified (Zaidi, 2015). The optimum model parameters (C, ε, RBF kernel γ) are determined by employing the grid search technique accompanying 10-fold cross-validation is given in Table 1.

Table 1 : Optimal model parameters for SVR to predict permeate rate, y in a reverse osmosis

Model	C	ε	$\lambda = 1/2\sigma^2$	Loss function	Type of Kernel	No. of training points	Quantity of SVs
Permeate rate, y	238.41	0.001	0.1142	ε - insensitive	RBF	50	27

After getting the optimum SVR parameters values, training and test course curves are plotted in Figs. 3 and 4. Predicted data points by the SVR-based model for each run in these figures has a good match with the observed data points. Furthermore, the SVR simulated results are plotted in Fig. 5 between the predicted values via SVR-based model and experimental values of permeate rate, y. It is found that the predicted training set and the test set hug the ideal fit line closely. The close proximity of the statistical values in Table 2 between the training set and the test set showed the excellent predictability and high generalizability of the SVR model.

Table 2 : SVR model evaluation based on statistical measures

Model Evaluation Indices	Training set	Test set
AARE (%)	3.35	1.95
(R^2)	0.9979	0.9984
(RMSE)	0.7930	0.5123
(SD)	0.0486	0.0165
(MRE)	0.0335	0.0195
Q^2_{LOO} (Training set), Q^2_{ext} (Test set)	0.9979	0.9983

4.2 Analysis of ANN Model

The input and the output layers neurons have been fixed in compliance with the independent and dependent variables of the specified problem while the optimum no. of the hidden layer neurons is determined 11 corresponding the minimal residual variance as depicted in Table 3. So, the optimum neural network architecture is 3-11-1 as shown in Fig. 6. The network is trained by using the fastest 'Levenberg-Marquardt' training algorithm with 'tan-sigmoid' and 'purelin' transfer function of the hidden layer and the output layer.

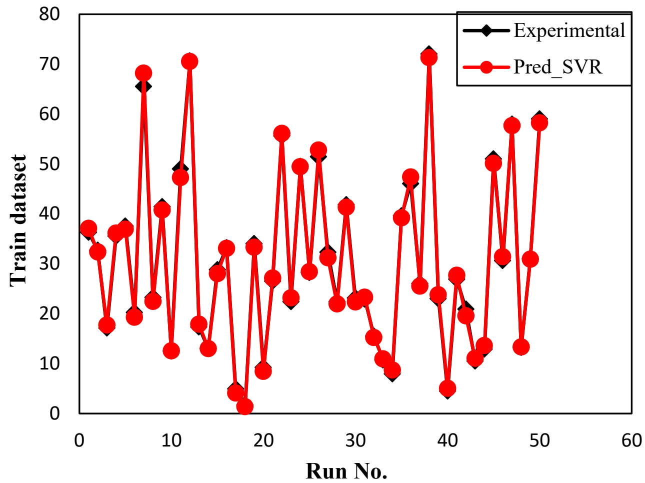

Fig. 3 : Training course curve

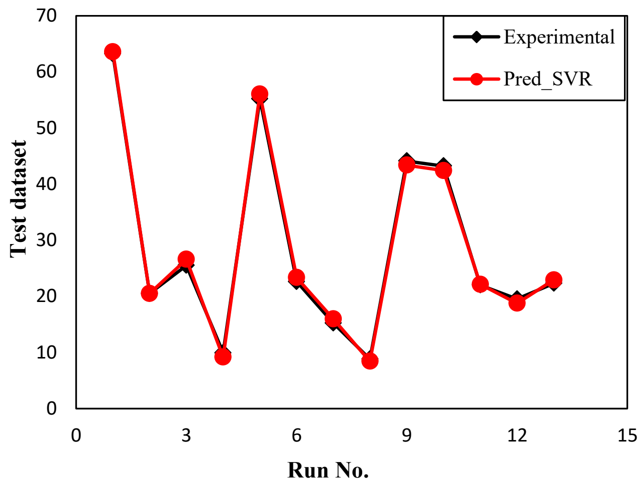

Fig. 4 : Test course curve

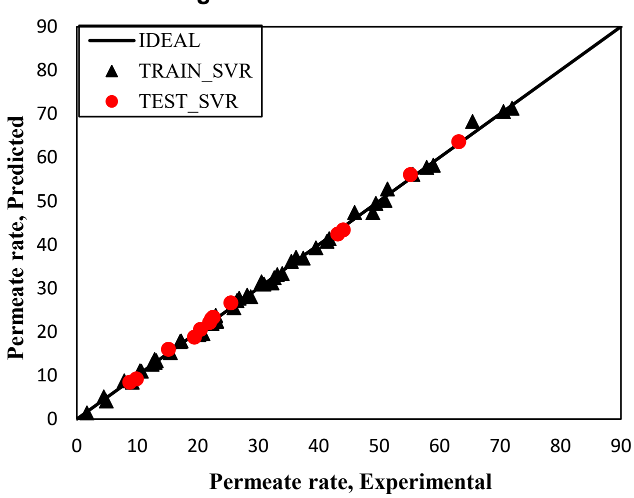

Fig. 5 : SVR simulation of permeate rate with optimal parameters

Parity plot in Fig. 7 has been constructed between the experimental data points of permeate rate of reverse osmosis and the predicted data points via the ANN model using the training set and the test set. This figure

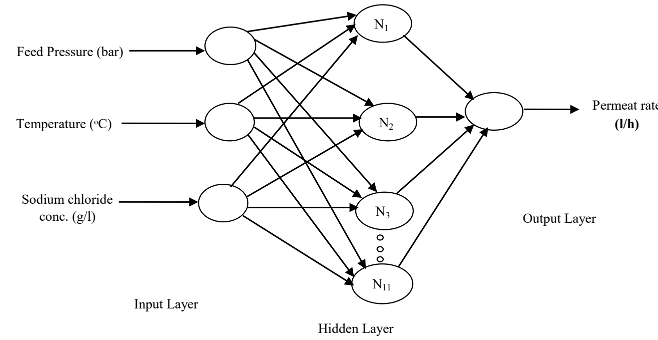

Fig. 6 : A schematic topology of 3-11-1 ANN architecture

demonstrates that the predicted data points for both the dataset closely fit the ideal line. The ANN model is evaluated based on statistical measures as presented in Table 4. For training set, AARE value of 4.29% is obtained while for test set it is 9.35%. Similarly, the R^2 value of 0.9957 and 0.9899 is found for the training set and the test set, respectively. The acquired values of statistical measures for the ANN model reveal the lower accuracy and poor generalizability for the test set (unseen data). This may be attributed to the ANN empirical risk minimization (ERM) principle, which reduces only training error and do not care about the model complexity. This leads to higher accuracy for the training set and lowers for the test (unseen) set which is the case of overtraining resulting in poor generalizability of the model.

Table 3 : Optimal no. of neurons for the hidden layer

No. neurons at the Hidden layer	% Residual variance
2	5.73274
3	3.06280
4	1.94560
5	1.58522
6	1.86118
7	1.01662
8	1.10942
9	1.04906
10	3.50541
11	0.74254 ← Optimal size
12	1.81376
13	0.88090
14	1.49842
15	1.48822
16	1.26217
17	0.79986
18	1.22642
19	1.15415

Table 4 : ANN model evaluation based on statistical measures

Model Evaluation Indices	Training set	Test set
AARE (%)	4.29	9.35
(R^2)	0.9957	0.9899
(RMSE)	1.2098	1.761
(SD)	0.0355	0.2139
(MRE)	0.0429	0.0935
Q^2_{LOO} (Training set), Q^2_{ext} (Test set)	0.9947	0.9899

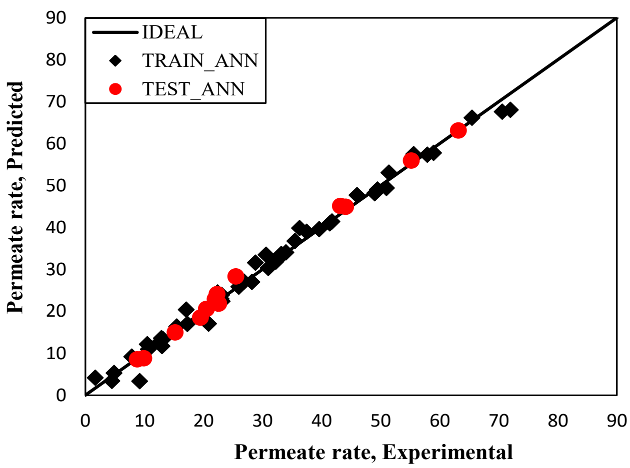

Fig. 7 : ANN simulation of permeate rate

4.3 Analysis of MLR Model

The most widely used MLR model has been developed using the training set of 50 samples and the obtained MLR model equation is given below:

$$y = -12.167 + 0.7385x_1 + 0.999x_2 - 0.7631x_3 \quad ...(5)$$

The independent variables has the significant effect on the permeate rate as shown in Eqn. (5).

Table 5 display the MLR model evaluation parameters. A high AARE value and low value of R^2 indicates the poor performance of the MLR model. Parity plot shown in Fig. 8 demonstrates that the predicted data points by the MLR model scatter around the ideal fit line.

Table 5 : MLR model evaluation based on statistical measures

Model Evaluation Indices	Training set	Test set
AARE (%)	24.04	52.04
(R^2)	0.9413	0.9157
(RMSE)	4.0322	4.8304
(SD)	0.1676	0.7541
(MRE)	0.2404	0.5204
Q^2_{LOO} (Training set), Q^2_{ext} (Test set)	0.9412	0.924

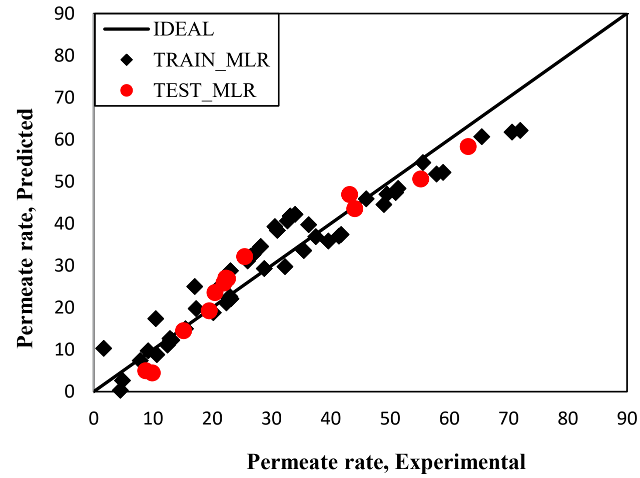

Fig. 8 : MLR simulation of permeate rate

4.4 Comparative Study

A comparative analysis of the performances of the AI-based models with the statistical MLR model over the test set (unseen data) is shown in Table 6. The acquired values of statistical measures reveal that the SVR model is absolutely accurate and possess high generalizability. The predicted data points by the SVR model hug the ideal fit line closely in comparison to the ANN and the MLR models. This is because the SRM principle of SVR model optimizes the generalization accuracy by a hade-off between the training error and the model complexity. While ERM principle of ANN and the conventional regression models minimize only the empirical or training error and do not care about the model complexity. This result in overtraining which means training set possess the higher accuracy and lower for the test set, which is a pointer to the poor generalizability of the model.

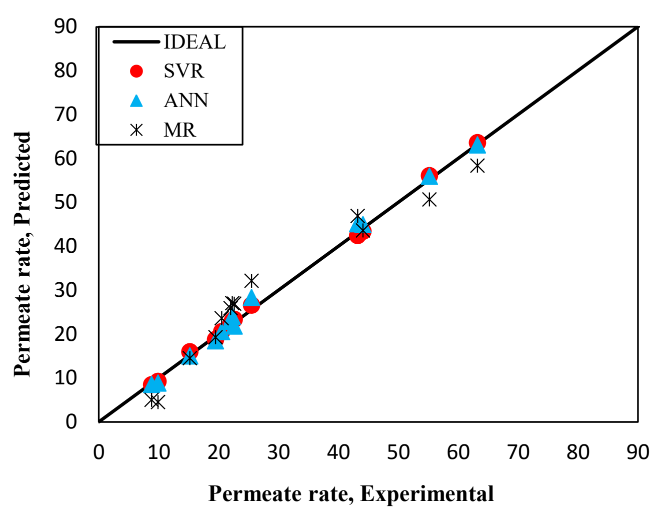

Fig. 9 : Comparison of the AI-based models with the MLR model over test dataset

Table 6 : Performance evaluations of the MLR, ANN and SVR models

Model Evaluation Indices	MLR	ANN	SVR
AARE (%)	52.04	9.35	1.95
(R^2)	0.9157	0.9899	0.9984
(RMSE)	4.8304	1.761	0.5123
(SD)	0.7541	0.2139	0.0165
(MRE)	0.5204	0.0935	0.0195

In order to measure the accuracy, another statistical measure i.e. relative error of these models is calculated with the help of the following equation:

$$\text{Relative error (\%)} = \frac{y_{predicted} - y_{experimental}}{y_{experimental}}$$

Fig. 10 shows the relative error of the developed MLR, ANN and SVR models for the permeate rate in reverse osmosis of the desalination process, y. It is observed that relative error for the SVR-based model is within 5% only while for the ANN model it is below 20% and for the MLR model relative error is around 120%. SRM principle of SVR is the reason behind the lowest value of relative error whereas ERM principle of ANN and MLR based models is responsible for the high relative error.

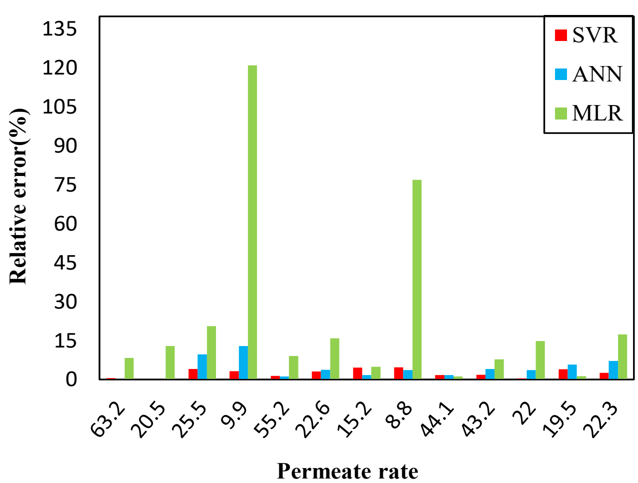

Fig. 10 : Relative error (%) of the MLR, ANN and SVR models for permeate rate

5. CONCLUSIONS

AI-based models viz. SVR and ANN models have been well developed for predicting the permeate rate in reverse osmosis of a desalination process. On the basis of the acquired values of statistical measures, training and test course curves, and relative error plot the predictability of the SVR model is observed to outperform the ANN and the MLR models. The outstanding predictability of the SVR model is due to the SRM principle upon which it is based. Furthermore, AI-based models, SVR in particular, can be useful in the fabrication and efficient design of a membrane-based wastewater treatment plant for salts and minerals rich effluent.

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REFERENCES

Abbas, A., Al-bastaki, N., (2005). Modeling of an RO water desalination unit using neural networks. Chemical Engineering Journal, 114(1-3): pp.139–143.

Chang, C.C., Lin, C.J., (2001). 2001. LIBSVM: A Library for Support Vector Machines. Department of Computer Science, National Taiwan University, Taipei, Taiwan: vol.2, pp.1-27.

Cherkassky, V., Ma, Y., (2004). Practical selection of SVM parameters and noise estimation for SVM regression. Neural Networks,17(1): pp. 113–126.

Devabhaktuni, V., Yagoub, M., Fang, Y., Xu, J., Zhang, Q.-J., (2001). Neural networks for microwave modeling: Model development issues and nonlinear modeling techniques. International Journal of RF Microwave Computer-Aided Engineering, 11(1): pp. 4–21.

Gunn, S., (1997). Support Vector Machines for Classification and Regression, ISIS Technical Report. University of Southampton: Southampton, UK: pp. 1–42.

Khayet, M., Cojocaru, C., Essalhi, M., (2011). Artificial neural network modeling and response surface methodology of desalination by reverse osmosis. Journal of Membrane Science, 368(1-2): pp. 202–214.

Lee, C.-Y., Chern, S.-G., (2013). Application of a Support Vector Machine for Liquefaction Assessment. Journal of Marine Science and Technology, 21(3): pp.318–324.

Madić, M., Miroslav, R., (2011). Methodology of Developing Optimal BP-ANN Model for the Prediction of Cutting Force in Turning. FACTA Universitatis Series Mechanical Engineering, 9(1): pp.21–32.

Musharavati, F., Hamouda, A.S.M., (2010). Application of artificial neural networks for modelling correlations in titanium alloys. Journal of Achievements in Materials and Manufacturing Engineering, 41(1-2), pp. 140–146.

Panchal, F.S., Panchal, M., (2014). Review on Methods of Selecting Number of Hidden Nodes in Artificial Neural Network. International Journal of Computer Science and Mobile Computing, 3(11): pp.455–464.

Parveen, N., Zaidi, S., Danish, M., (2017). Development of SVR-based model and comparative analysis with MLR and ANN models for predicting the sorption capacity of Cr(VI). Process Safety and Environmental Protection, 107: pp. 428–437.

Salgado-Reyna, A., Soto-Regalado, E., Gómez-González, R., Cerino-Córdova, F.J., García-Reyes, R.B., Garza-González, M.T., Alcalá-Rodríguez, M.M., (2015). Artificial neural networks for modeling the reverse osmosis unit in a wastewater pilot treatment plant. Desalination and Water Treatment, 53(5): pp.1177–1187.

Shi, X.Z., Zhou, J., Wu, B.B., Huang, D., Wei, W., (2012). Support vector machines approach to mean particle size of rock fragmentation due to bench blasting prediction. Transactions of Nonferrous Metals Society of China, 22(2): pp.432–441.

Smola, A.J., Schölkopf, B., (2004). A tutorial on support vector regression. Statistics and Computing, 14(3): pp.199–222.

Vapnik, V., Golowich, S.E., Smola, A., (1996). Support Vector Method for Function Approximation, Regression Estimation, and Signal Processing. Advances in Neural Information Processing Systems, 9: pp.281–287.

Zaidi, S., (2015). Novel application of Support Vector Machines to model the two phase-boiling heat transfer coefficient in a vertical tube thermosiphon reboiler. Chemical Engineering Research and Design, 98: pp.44–58.

Economic Feasibility Study of Horticultural Wastes for Chromium Adsorption from Tannery Wastewater

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ABSTRACT

Present study shows the best horticultural wastes management using these wastes to adsorb chromium from wastewater. Waste water treated this way can be reused for various purposes which is indirectly a social welfare. These low cost adsorbents also reduce the cost of final product and the water contaminated by chromium becomes free of chromium which ultimately joins our natural streams preventing them from pollution. A successful trial is achieved for the estimation of the cost of adsorption while studying economic feasibility of various horticultural wastes like mango (Mangifera indica) waste in both the forms like seed and seed shell waste and papaya (Carica papaya) to remove hexavalent chromium from tannery wastewater. The cost for a unit gram of hexavalent chromium removal from wastewater using these adsorbents such as; mango (Mangifera indica) both seed and seed shell waste and papaya (Carica papaya) were estimated as Rs.1.38, Rs.4.03, Rs.2.37 respectively. The investigations show that the cost of using these agro wastes as adsorbents is very very less as compared to commercial activated carbon's cost i.e. Rs.142.145.The prepared adsorbents from horticultural wastes proper waste management. Adsorbents mango (Mangifera indica) both seed and seed shell wastes and papaya (Carica papaya) wastes have the positive enthalpy ΔH values 2.129, 1.836 and 2.433 respectively indicated the endothermic sorption with strong attachment, the positive free energy change ΔG; 2.312, 1.794 and 2.97 claim the random feasibility. Attachment with adsorbent surface shows the degree of freedom loss with negative value of entropy (ΔS) for seed of mango waste (-0.739), seed shell of mango waste (-0.087) and seeds of papaya waste (-0.0378). The low cost adsorption of chromium using horticultural wastes from aqueous solutions is a sustainable solution with 6 "R".

Keywords *: Sustainable, aqueous, chromium, pollution, estimation etc.*

1. INTRODUCTION

Heavy metals toxicity of surface and ground water has become a global issue specially after the establishment of Environmental protection Agency in 1970. It has attracted the researchers interest to focus on heavy metals emission control at source within safe standards of quality water. Due to negligence of pollution regulations, impact on ozone layer, air pollution, drinking water qualities a number of projects are not given environmental clearance in developing countries like India. So the projects of environmental concern should apply novel technologies with pollution control at source only.

Researchers time to time have focused sustainability goals like pre and post concerns, heavy metals emission control at source, recovery for reuse, solid agro waste management, value added conversion of wastes to achieve environmental pollution control and maintaining economy in research methodology. It is basically "Six Rs" that is recovery, reutilization, revaluation, remediation, recirculation, reuse of horticultural wastes to remove heavy metals toxicity, approach.

Many industries use heavy metals in various processes and their traces coming out of effluents directly or indirectly in ion or compounds form join our environment through air or water. These heavy metals when consumed by living beings adversely affect their health. Our study is confined here with chromium heavy metal removal only. Trivalent chromium is very helpful to metabolize sugar (Katz, 1991) but Cr (VI) is quite dangerous and carcinogenic in nature. Electroplating industries, pigmenting and wood preservation industries, leather industries and tanneries etc. release chromium in their wastewater and because of their costly removal by activated carbon the industrialists release this effluent wastewater contaminating natural water bodies and it is most often in developing countries.

Chromium adsorption from industrial effluents using horticultural wastes as adsorbent has attained a great popularity because of being very efficient and cheaper. It best suits to generate quality wastewater of safe disposal standards and these horticultural adsorbents can also be reused. Though these adsorbents are plentily available at very low cost so generally their reuse has not been promoted at all (Ayub,et.al., 2014, 2003, 2002, 2001, 1999, 1998; Sharma, et al., 2019, 2017, 2016, 2016, 2015, 2013; Raji, et al., 1998; Ajmal, et al., 2000, 1995). In last recent years many researchers working in this area of heavy metal removal have proven horticultural wastes as potential adsorbents (Ayub S., et al., 2014, 2006,2002, 2001,1999, 1998; Sharma, P.K., et al., 2019, 2017, 2016, 2016, 2015, 2013, 2010; Veena Devi B., et al 2012, Baskaran P. K., et al 2010; Camino, et al., 2000; Drake, et al., 1996; Weber, 1996; Siddiqui, et al., 1994; Chand, et al., 1994; Deo, et al., 1992; Vaishya and Prasad, 1991; Shukhla, and Sakhardane, 1991; Periasamyet al., 1991; Huang, et al., 1975). These horticultural wastes have replaced the conventional and expensive activated carbon as adsorbent.

Though during various processes in tanneries chemicals such as SO_2, $NaHSO_4$ and sodium meta-bisulfate etc; are used to convert dangerous chromium (VI) to beneficial chromium (III). The imbalance of surface forces dominates in physical adsorption process. An interface is developed between the molecules of adsorbate in wastewaters and solid surfaces of adsorbents capillaries and as a result of attachment a chemical adsorption is followed due to residual valence forces of the base molecules. The recent researchers have observed that higher molecular weighted substances more readily adsorbed on adsorbent surfaces so the adsorption of heavy metals is very efficient. The adsorption of chromium is efficiently achieved on to the adsorbents solid surfaces or in to the undulations and capillaries. A quick equilibrium interface concentration is achieved by slow diffusion. Though the adsorption varies with varying combinations of adsorbent and adsorbate alongwith interference of other interfering ions in complex wastewaters.

Though a lot of literature is available on low cost adsorptions but none of the researchers has estimated the cost of adsorbents so as to prove their economy. First time it is tried to analyze the adsorption cost so as to coin the economic feasibility of the so called horticultural wastes used as adsorbent to remove chromium from the tannery effluents. The study comprises of estimation of cost and economical feasibility of different agro wastes like mango (Mangifera indica) both seed waste, seed shell waste and papaya (Carica papaya) which were used to adsorb Cr (VI) from tannery waste water. Various parameters like adsorbent dose, pH, temperature, chromium initial concentration, interaction time, sorbent range of size and mixing rpm etc. were renovated during adsorption. The sorbents surfaces were described prior to batch adsorption and later; using Scanning Electron Microscopy (SEM) analysis. Thermodynamic characterization had also been made.

2. MATERIALS AND METHODS

2.1 Adsorbents and Sample Preperation

Horticultural wastes of mango (Mangifera indica) both seed, seed shell and papaya (Carica papaya) seeds waste were used to adsorb chromium (VI) from leather industries effluent wastewater performing batch experiments in laboratory.

2.1.1 *Preparation of Adsorbents*

Around fifteen days sun dried adsorbents were oven dried for three days keeping 95°C oven temperature at rate five hours per day. To remove alkaline and lignin alternative wash of 0.1N H_2SO_4 and 0.1N NaOH was given and each time the adsorbents were rinsed with distilled water.

Then alternatively washed by 0.1N NaOH and 0.1N H_2SO_4 followed by distilled water wash to remove all lignin and alkaline. Desicators were used to store these well dried adsorbents for further use.

2.1.2 *Experimental*

Batch process for the adsorption of chromium were performed at 28° C during summer to observe the effects of adsorbent dosage, pH, adsorbent grain size range, interaction period, temperature and the mixing speeds in rpm with a Chromium Standard Solution for various concentrations and this way all the above said parameters were optimized aiming to apply them for actual tannery effluent wastewater. After optimization of the above said parameters the filtrates passing through specific filter paper Whatman No.1 were observed for remaining content of chromium using AAS at CED, EE section, Z.H.C.E.T., AMU, Aligarh (India).

2.2 Thermodynamic Feasibility Analysis

$\Delta G = - RT \ln K$ The Gibb‟s free energy equation at equilibrium the thermodynamic constants showed the adsorption feasibility. Here, ΔG is the free energy change in joule/mole, R; the universal gas constant as 8.314 and T the absolute temperature. ΔG versus T graphs were drawn for adsorbents and best fit lines related to; $\Delta G = \Delta H - T.\Delta S$ [Sharma and Ayub, 2019]

Were, enthalpy change ΔH, entropy change for activation ΔS (Sharma and Ayub 2019). Gibb's free energy versus temperature in Kelvin plots as Fig.1 MSWTP for mango seed waste, Fig. 2, MSSWTP for mango seed shell waste and Fig. 3 PSTP for papaya seeds waste as adsorbent with best fit lines to study feasibility of adsorption; ΔS, ΔG and ΔH were determined at 301 K as mentioned in Table 1.

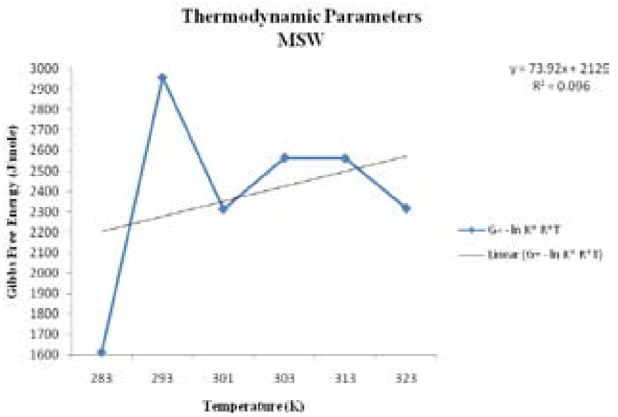

Fig. 1 : MSWTP

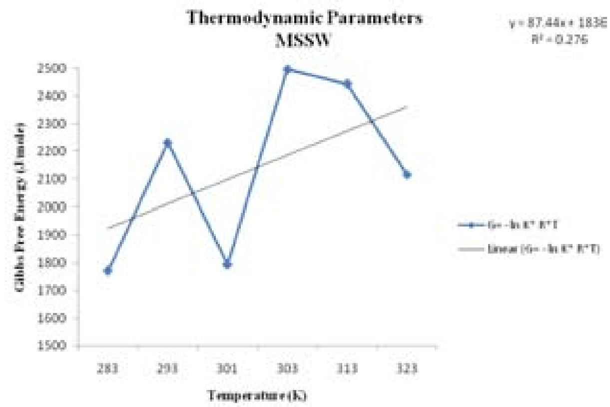

Fig. 2 : MSSWTP

Positive enthalpy ΔH values 2.129, 1.836 and 2.433 for each adsorbent indicate the adsorption endothermic with powerful attachment; the positive ΔG values 2.312, 1.794 and 2.97 indicate the random feasibility and the negative value of entropy ΔS as -0.739, -0.087 and -0.0378 indicates the loss of degree of freedom (Sharma and Ayub 2019, Ayub, et al, 2006) Table 1.

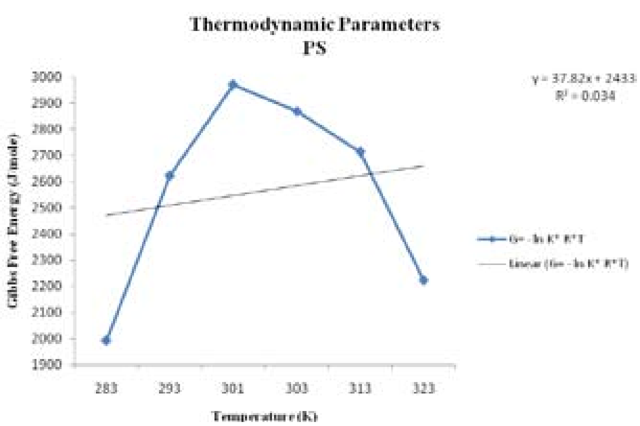

Fig. 3 : PSTP

2.3 Langmuir Isotherms

The original equation of Langmuir $q_e = \frac{(Q_0 K_L C_e)}{(1+K_L C_e)}$ converted to linear form as $\frac{1}{q_e} = \frac{1}{q_o} + \left(\frac{1}{q_0 K_L}\right)\left(\frac{1}{C_e}\right)$

Here, Ce is the initial adsorbate concentration in mg/l, Qe the mass of adsorbate attached on to a gram of sorbent expressed in mg/gm, Qo single sheet coverage sorbent capacity in mg/g determined to calculate the cost of sorption process. For Langmuir's constant values q_{max}, K_L best fit line's intercept and slope of the Langmuir curve were used. R_L, showed sorption feasibility i.e. its zero value for irreversible, zero to 0.99 favorable and more than one unfavourable.

$R_L = 1/[1+\{1+K_L.C_o\}]$ Where C_o is adsorbate concentration in beginning taken 30 mg/l and K_L is a numeric equilibrium constant which relates sorption energy (Sharma and Ayub 2019, Dada, et al, 2012). The Langmuir curves for *Mangifera indica* both seed and seed shell waste and *Carica papaya* have been shown in Fig. 4, 5 and 6 respectively with constants values of adsorbents as in Table 1.

Table 1 : Thermodynamic Parameters and Langmuir Constants

301 K	Langmuir Constants					Thermodynamic Parameters		
AdSorbent	(Max. single layer sorption, mg/g) qmax	1/q0	(Langmuir Constant) KL	R_L (Favourable if 0< RL<1)	R^2 (Perfect correlation) (Should be<1)	ΔG (KJ/mole)	ΔH (KJ/mole)	ΔS (KJ/mole)
MSW	18.86792	0.053	0.1920	0.129	0.977	2.312	2.129	-0.0739
MSSW	7.692308	0.130	0.4580	0.064	0.977	1.794	1.836	-0.087
PS	9.345794	0.011	0.4050	0.071	0.986	2.970	2.433	-0.0378

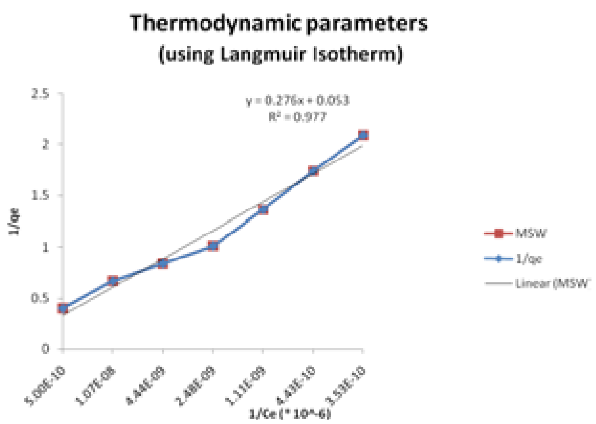

Fig. 4 : MSWL

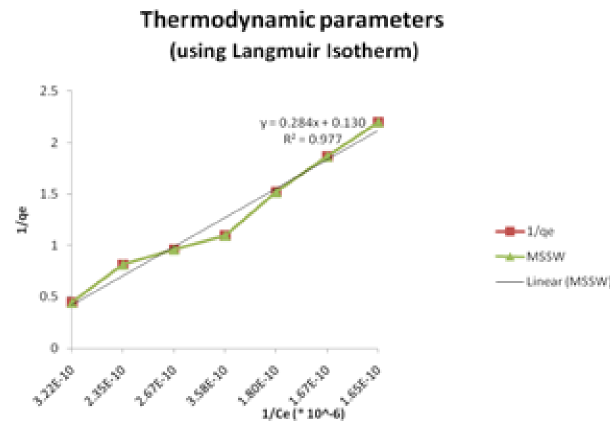

Fig. 5 : MSSWL

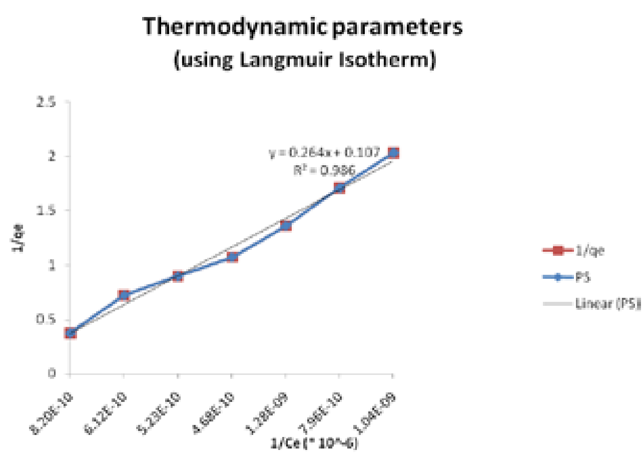

Fig. 6 : PSL

2.4 Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy for mango (Mangifera indica) both seed, seed shell waste and papaya (Carica papaya) seed waste adsorbents was performed to view the surface of sorbents both the times before adsorption and after adsorption at USIF Centre, AMU, Aligarh. The samples were gold coated as found non-conducting before SEM. SEM analysis revealed sorbents showing sufficient surface with undulations for binding adsorbate.

3. DISCUSSION AND RESULTS

Various adsorption process affecting parameters like pH, adsorbent dose, initial concentration of adsorbate, interaction time, size of adsorbent, temperature and agitation rates etc. were optimized performing batch experiments and then Langmuir Isotherms as above drawn to determine the cost and feasibility of the sorption process. Thermodynamic study indicated the feasibility of the adsorption.

3.1 Optimum Values of Process Affecting Parameters

- pH 1.5-3.0

The highest percentage of adsorption occurred between 1.5-3.0 pH (Sharma and Ayub, 2019, Mahesh, et al., 1999, Sharma et al 2016, Sharma, et al., 1993).

- Adsorbent Dose 30 g/L

The adsorbent doses 20 g/L, 30 g/L and 40 g/L were best observed for mango seed, its seed shell and papaya seed wastes respectively so the average of these doses 30 g/l was also good result providing. (Sharma and Ayub, 2019, Ayub, S. et al., 2014, 2002; 2001; Rao, et al., 2002; Mall, 1992; Bansal and Sharma, 1992).

- Initial Concentration of Adsorbate

In fact initial concentration of chromium coming out of a tannery as an effluent is; not at all in our control yet, not only to understand at what initial concentration of chromium our adsorbent will work efficiently but this study was also very important from the point view of dynamic systems design.

The treatment efficiency of a dynamic system can be enhanced by dilution of existing initial chromium concentration as per requirement.

- Contact Time 45 Minutes

Chromium removed almost 90% was observed in first 45 minutes. (Sharma and Ayub, 2019, Ayub, S. et al., 2014)

- Grain Size of Adsorbent 600 μm to 300 μm (Sharma and Ayub, 2019; Ayub, S. et al., 2014)

Average grains from 600 μm to 300 μm found optimum.

- Temperature 25^{0}C to 30^{0}C (Sharma and Ayub, 2019, Ayub, S. et al., 2014)

Maximum adsorption observed between 25^{0}C to 30^{0}C as maintained in batch set ups.

- Agitation Rate 80 to 100 rpm (Sharma and Ayub, 2019, Ayub, S. et al., 2014)

At initial stage results for mixing speed between 80 to 100 rpm were observed best.

3.2 Physical Feasibility of Adsorption

(+) value of ΔH means endothermic adsorption. ΔG positive means random feasibility. ΔS negative for all the adsorbents at equilibrium revealed loss of degree of freedom may be due to watering of the adsorbent surface (Baisakh, et al., 1996, Baisakh, et al., 2002)

The Langmuir adsorption isotherms for mango (Mangifera indica) both seed, seed shell waste and papaya (Carica papaya) were plotted as shown in Fig. 1, 2 and 3. R_2 value for Langmuir was 0.977 (MSW), 0.977 (MSSW) and 0.986 (P_S). Using Langmuir Isotherms for mango (Mangifera indica) both seed, seed shell waste and papaya (Carica papaya) the maximum monolayer coverage (Q_0) were determined as 18.86792 mg/g, 7.692308 mg/g and 9.345794 mg/g respectively and also the factors of separation (R_L) were computed as 0.129, 0.064 and 0.071 indicating the sorption process favored(Sharma and Ayub, 2019, Ayub, S. et al., 2014).

4. COST ESTIMATION

Cost estimation is very much useful especially to decide and fix the environment protection criteria provided probable environmental effects on application adsorption processes. No researcher thought of this very important point. The sorption process cost mainly depends on the adsorbent cost. Activated carbon has been in long practice to adsorb heavy metals from wastewater. It was very costly treatment using activated carbon for removal of chromium and that is why it is not affordable in poor countries. It is also not available in plenty against the demand which is increasing day by day. So keeping various factors such as availability, environmental, economy, feasibility, efficiency, agricultural waste management etc. in mind the researchers of this study determined the cost of removal of chromium from wastewater using mango (Mangifera indica) both seed, seed shell waste and papaya (Carica papaya) as adsorbent and compared this cost to the activated carbon (Sharma and Ayub, 2019, Changani, 2014, Gupta, 2008). The estimated cost, economy and feasibility of MSW, MSSW and PS as chromium adsorbents from aqueous solutions is given in Table 2 and 3.

All the costs of various processes of methodological steps such as physical activation, chemical activation, oven drying, heating, grinding etc. have been taken in to account and as a result the cost of one kg ready adsorbent was found as Rs.25.88, Rs.31.05, Rs.22.17 for mango (Mangifera indica) both seed, seed shell waste and papaya (Carica papaya) respectively as shown in Table 1.

The cost of conventional activated carbon in the market is Rs. 600 for one kilogramg. To remove 1 gm chromium from tannery effluents the estimated cost of sorbents; MSW, MSSW and PS is ahown in Table 3.

Table 3 : Unit grams chromium removal cost.

Sorbent	Sorption Capacity (mg/g)	Sorbent Cost (Rs./ kg)	Sorbent Cost for unit g chromium removal (Rs.)
MSW	18.86	25.88	1.38
MSSW	7.70	31.05	4.03
PS	9.35	22.17	2.37

These estimated costs of the adsorbents; MSW, MSSW and PS are Rs.1.38, Rs.4.03, Rs.2.37 respectively. These costs are very low as compared to that of activated carbon Rs.142.145. The prepared adsorbents are developed from agro and horticultural wastage which is also a

Table 2 : Cost Estimation of Unit Kg Horticultural Waste Adsorbents (MSW, MSSW, PS)

Process	Rate	MSW		MSSW		PS	
(Rs.)		Quantity	Cost	Quantity	Cost	Quantity	Cost
H_2SO_4	6.00 per L	1.5 L	9.00	1.5 L	9.00	1.0	6.00
NaOH	1.60 per L	4.0 L	4.80	4.0 L	6.40	2.5	4.00
Drying Cost	5.80 kwh	0.5 kwh 700 5 h	2.90	0.6 kwh 900 5 h	3.48	0.6 kwh 900 5 h	3.48
Heating Cost	5.80 kwh	0.6 kwh 900 5 h	3.48	0.6 kwh 900 5 h	3.48	0.6 kwh 900 5 h	3.48
Grinder	5.80 KWh	0.4 kwh 30 min	2.32	0.8 kwh 1 hr	4.64	0.4 kwh 30 min	2.32
Net Cost (Rs.)		22.50		27.00		19.28	
Other Overhead Cost (Rs) (15% of Net Cost)		3.38		4.05		2.89	
Total Cost (Rs)		25.88		31.05		22.17	

burden on farmers to dispose and manage. Horticultural waste management is an environmental issue. If these horticultural wastes are used for this good cause they are no doubt value added. If burnt as usual farmers do in developing countries lot of carbon di oxide gases release threatening environment and local climate which is of great environmental and climatic concern but also hampers gardens proper growth. Chromium removed at source at low price reduces cost of processing and final product in the industry both. The great advantage to the environment is that the process is very ecofriendly. The water so refined meeting the required standards can be reutilized for various process of industry again indirectly benefitting industrialists and hence tanneries can play a big role against unemployment and environmental and natural streams pollution at such a low cost. This research opens the pathways of the Sustainable development of industries, society and nation. All the required aspects of sustainable development like social, environmental and economical are being achieved. It is the beauty of this research (Sharma and Ayub, 2019, Changani, 2014, Gupta, 2008).

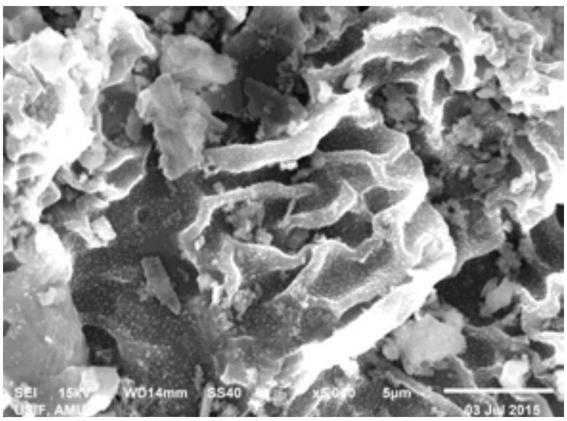

Fig. 7 : MSW Before Adsorption

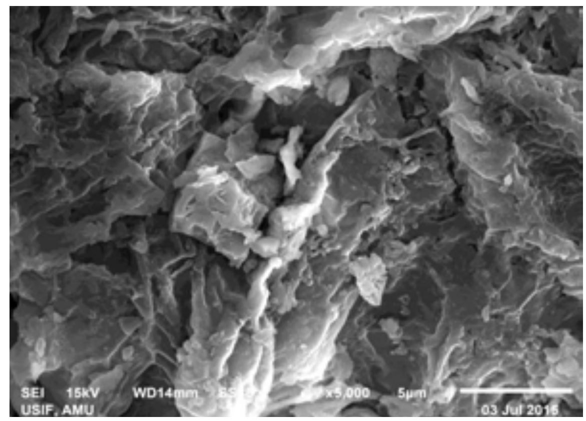

Fig. 8 : MSW After Adsorption

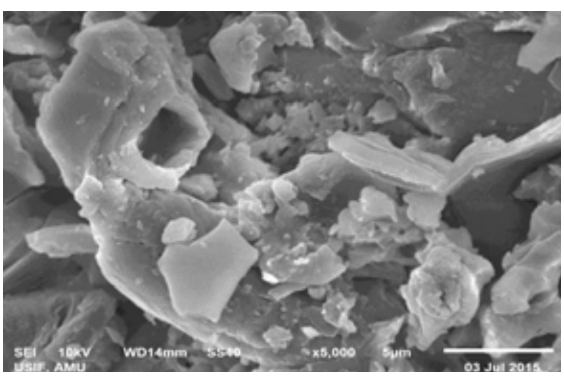

Fig. 9 : MSSW Before Adsorption

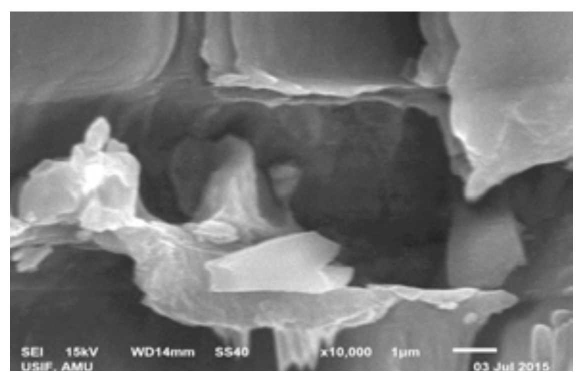

Fig. 10 : MSSW After Adsorption

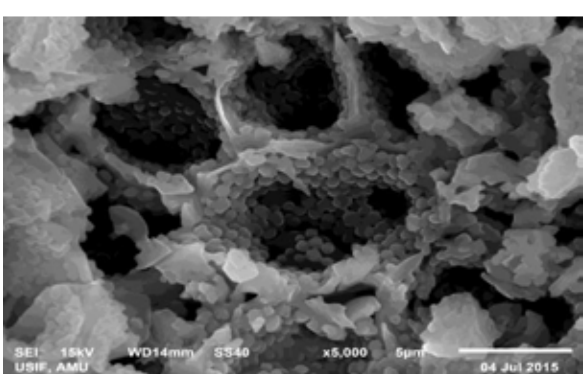

Fig. 11 : PS Before Adsorption

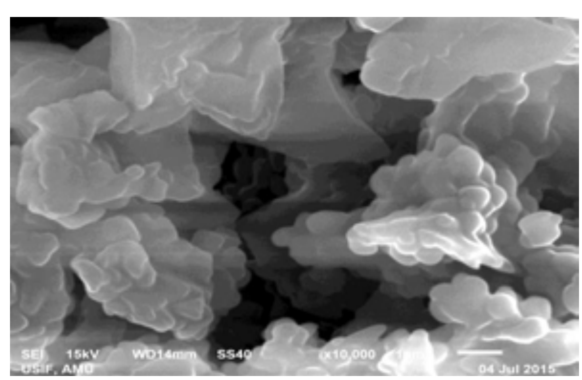

Fig 12 : PS After Adsorption

CONCLUSIONS

That horticultural wastes; MSW, MSSW and PS have been verified potential adsorbents toxic chromium from tanneries and electroplating industries wastewater discharges. The chromium adsorption efficiency of these horticultural waste was the highest in the range of pH 1.5 to 3.0. The positive enthalpy (ΔH) calculated proves adsorption to be endothermic and strong binding. Positive values of (ΔG) i.e. Gibb's free energy proves the adsorption process of non-spontaneous type. Entropy ΔS found negative indicated poor attachment for chromium on to the surface of horticultural adsorbents. The horticultural wastes for the chromium sorption from aqueous solutions of tannery waste were found to be cheaper than conventional activated carbon. Additional advantage; the methodology is dual beneficial, i.e., waste management in horticulture conserving gardens with protection of environmental pollution through waste open burning. Scanning Electron Microscopy proved plenty undulated surface and irregular cavities within which chromium found captured.

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REFERENCES

Ajmal, M., Rao, R.A.K., Ahmad, R., and Ahmad J; (2000). Adsorption studies on Citrus reticulata (fruit peel of orange): removal andrecovery of Ni (II) from electroplating wastewater. Journal of Hazd.Materials, Vol. 49(1-2), p. 117-131.

Ajmal, M., Rifaqat, A. K. R., and Bilquees, A.S. (1995). Adsorption and removal of dissolved metals using pyrolusite as adsorbent. Environmental Monitoring and Assessment, Vol. 38, p. 25-35.

Ayub S., Khorasgani F. Changani., (2014). Adsorption process for wastewater treatment by using coconut shell. International Journal of Civil, Structural, Env & Infr. Engg research development (IJCSEIERD), Vol. 4(3), p. 21-34, ISSN 2249-6866

Ayub, S., Ali, S. I., and Khan, N. A. (1998). Treatment of Wastewater by Agricultural Wastes. Environmental Pollution Cont. Journal, Vol. 2(1).

Ayub, S., Ali, S. I., and Khan, N. A. (1999). Extraction of Chromium from the wastewater by Adsorption. Environmental Pollution Cont. Journal. Vol. 2(5).

Ayub, S., Ali, S. I., and Khan, N. A. (2001). Efficiency Evaluation of Neem bark (Azadirachtaindica) bark in the treatment of industrial wastewater. Environmental Pollution Cont. Journal, Vol. 4(4), p. 34-38.

Ayub, S., Ali, S. I., and Khan, N. A. (2002). Adsorption studies on the low cost adsorbent for the removal of Cr (VI) from the electroplating industries. Environmental Pollution Cont. Journal, Vol. 5(6).

Ayub, S., Ali, S. I., and Khan, N. A. (2003). Chromium removal by adsorption on coconut shell. .Journal of Indian association for Environmental Management, NEERI, Vol. 30, p. 30-36.

Ayub, S., Ali, S.I. and Khan, N. A. (2006). Comparative study of different agro based adsorbents for the treatment of wastewater. Current World Environment, Vol. 1(2), p. 109-116.

Ayub, S., Sharma, P.K., Tripathi, C.N., (2014). Removal of Hexavalent Chromium Using Agro and Horticultural Wastes as low Cost Sorbents from Tannery Wastewater: A Review. International Journal of Research in Civil Engineering, Architecture & Design, Vol. 2(3), p. 21-35, ISSN Online:2347-2855, Print:2347-8284, DOA : 17082014.

Baisakh, P.C., Patnaik, S.N. (2002). Removal of Hexavalent chromium from aqueous solution by adsorption on coal char. Ind. J. of Env. Hlth, Vol. 4(3), p. 189-196.

Baisakh, P.C., Patnaik, S.N., and Patnaik, L.N., (1996). Removal of COD from textile mill effluent using fly ash. Ind. J. Env. Protection, Vol. 16 (2), p. 135-139.

Bansal, T.K., and Sharma, H.R. (1992). Chromium removal by adsorption on rice husk ash. Ind. J. Environ. Protec., Vol. 13 (3), p. 198-201(Quoted by Rai, et al., 1995),.

Baskaran P.K., Venkatraman B.R., Hema M, Arivoli S (2010). Adsorption studies of copper ion by low cost activated carbon. J. Chem. Pharm. Res., Vol. 2(5), p. 642-655.

Camino, G., Paserini, A., and Toscano, G (2000). Removal of toxic and Cr (VI) from aqueous solution by hazelnut shell. Vol. 34(11), p. 55-2962.

Chand, S., Aggarwal, V. K., Kumar, P. (1994). Removal of Hexavelent Chromium from the Wastewater by Adsorption. Indian J. Environ. Hlth. Vol. 36, 3, p. 151-158.

Dada, A.O, Olalekan, A.P, Olatunya, A.M., DADA, O (2012). Langmuir, Freundlich, Temkin and Dubinin–Radushkevich Isotherms Studies of Equilibrium Sorption of Zn2+ Unto Phosphoric Acid Modified Rice Husk" IOSR Journal of Applied Chemistry (IOSR-JAC) ISSN: 2278-5736. Volume 3, Issue 1(Nov. – Dec. 2012), PP 38-45.

Deo, N., Ali, M. (1992) "Use of a low cost material as an adsorbent in the removal of Cr (VI) from dilute aqueous solution". Indian J. of environ. Pollution, Vol. 12, 6, p. 439-441.

Drake, D. O., S, Lin, G. D Rayson., and Jackson, P. J. (1996). Chemical modification and metal binding studies of daturainnoxia. Env. Sc. and Tech. Vol. 30(1), p. 110-114.

Gupta, S. and Babu, B.V., (2008). Adsorption of Cr(VI) using activated neem leaves: kinetic studies. Adsorption, February 2008, Vol. 14(1), p. 85-92. http://link.springer.com/article/10.1007/s10450-007-9057-x

Katz, S. A. (1991). The analytical biochemistry of chromium. In: Environmental health perspective. NIH publication, Vol. 92, p. 13-16.

Mahesh, S., Rama, B.M., Praveen, K.N.H. and Usha, L.K., (1999). Adsorption kinetics of Di hydric Phenol Hydroquinone on Activated Carbon. Indian J. Environ. Hlth. Vol. 41(4), p. 317-325.

Mall, I. D. (1992). Studies on the treatment of pulp and paper mill effluent, Ph. D. theses. Banarus Hindu University, Varanasi, India (Quoted by Rai, et al., 1995).

Periasamy, K., Srinivasan, K., and Murugan, P. K. (1991). Studies on chromium (VI) removal by Activated Groundnut Husk Carbon. Indian J. Env. Hlth, Vol. 31(4), p. 433-439.

Raji, C., and Anirudhan, T. S. (1998). Sorptive behaviour of Chromium (VI) on saw dust carbon in aqueous media. Ecol. Env. And Cons., Vol. 04(1), p. 2-33.

Rao, M., Parwate, A.V., and Bhole A.G. (2002). Utilization of low cost adsorbents for the removal of heavy metals from wastewater. Env. Poll. Cont. Jour. Vol. 5 (3), p. 12-23.

Sharma, P.K. and Ayub, S. (2019) “The Cost Analysis and Economic Feaibility of AGRO Wastes to Adsorb Chromium (VI) From Wastewater,” International Journal of Civil Engineering and Technology (IJCIET), 10(2), 2019, pp.2387–2402. http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=10&IType=2

Sharma P.K., Ayub S. and Tripathi C.N., (2016 a). Isotherms describing physical adsorption of Cr (VI) from aqueous solution using various agricultural wastes as adsorbents, Cogent Engineering, Taylor and Francis. Sharma et al., Cogent Engineering, Vol. 3, p. 1186857. http://dx.doi.org/10.1080/23311916.2016.1186857

Sharma P.K., Ayub S., Tripathi C.N., (2015). Sorption Studies of Synthesized Horticultural Waste Seeds for Removal of Hexavalent Chromium from Aqueous Solutions. Int. J. Environ. Sci. Toxic. Res. Vol. 3(7), p. 101-114.

Sharma P.K., Ayub S., Tripathi C. N., (2017). Physisorption of Chromium from Aqueous Solutions Using Agro and Horticultural Wastes as Adsorbent, International Journal of Applied Environmental Sciences ISSN 0973-6077, Vol. 12(4), pp. 607-631 https://www.ripublication.com/ijaes17/ijaesv12n4_04.pdf

Sharma P.K, Ayub S., Tripathi C.N., and Ajnavi, S. (2016). Removal of Chromium (VI) From Aqueous Solutions Using Discarded Solanum Tuberosum as Adsorbent. Research Inventy: International Journal of Engineering and Science Vol.6, Issue 11 (December 2016), p. 05-15 Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Sharma P.K., Dubey S.K., Rehman Z. (ETSE-2010). A Study on Arsenic Removal from Ground Water by Adsorption Process, International Conference on Emerging Technologies for Sustainable Environment, (ETSE-2010), Department of Civil Engineering, A.M.U. Aligarh, India, October 29-30, 2010, in collaboration with Lasierra University, USA and Asia Pacific International University, Thailand. Proceedings published, p.164-167.

Sharma, D.C., and Forster, C.F. (1993). Removal of Hexavalent chromium using Sphagnummors peat. Wat. Res, Vol. 27(7), p. 1201-08.

Sharma, P.K., Ayub, S., and Tripathi, C.N., (2013). Agro and Horticultural Wastes as Low Cost Adsorbents for Removal of Heavy Metals from Wastewater: A Review, International Refereed Journal of Engineering and Science (IRJES), Vol. 2(8), p. 18-28.

Sharma, P.K., Khan, N.A. and Ayub, S.; (2012). Methematical modelling in anaerobic process. International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) ISSN 2249-6866, Vol. 2(3), p. 52-65.

Sharma, P.K., Khan, N.A. and Ayub, S;; (2012) “Modeling of cod reduction in a UASB reactor” :Global J. of Engg. & Appl. Sciences, 2012: Vol. 2(2), p. 178-182, ISSN 2249-2631(online): 2249 2623(Print) - Rising Research Journal Publication.

Shukhla, S. R., Sakhardane, V. D. (1991). Column studies on metal iron removal by dyed cellulosic materials. Vol. 11(4), p. 284-289.

Siddiqui, Z.M., Paroor, S. (1994). Removal of Cr (VI) by different adsorbents A comparative Study. IJEP, Vol. 14(4), p. 273-278.

Vaishya, R., and Prasad, S. C. (1991). Adsorption of copper on saw dust”. Indian J. Envoron. Prot.,Vol. p. 11, 284-299.

Veena Devi B, Jahagirdar AA, Zulfiqar Ahmed MN (2012). “Adsorption of Chromium on Activated Carbon Prepared from Coconut Shell ” International Journal of Engineering Research and Applications (IJERA), Vol. 2(5), September-October 2012, pp.364-370 ISSN: 2248-9622 www.ijera.com

Identification of Groundwater Potential Recharge Zones Using Remote Sensing and Geographical Information System: Tiruppur District, Tamil Nadu

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ABSTRACT

Groundwater management studies integrate the concept of spatial planning by using GIS (Geographical Information system). There is a need to bridge the gap between existing demand and supply for concreting the sustainability pillars. This paper gives an attempt to identify groundwater recharge potential zones and propose artificial recharging sites spatially for the Tiruppur District, Tamil Nadu. Through Arc GIS, weighted overlay analysis has been done which requires seven thematic layers such as soil, lineament, drainage density, geomorphology, land use, geology and slope and classified into three classes such as good, moderate and poor. This technique of identifying potential zones is one of the effective ways of groundwater management. Groundwater recharge structure like check dams, boulder bunds and percolation tanks has been proposed spatially.

Keywords *: GIS, Potential Groundwater zones and Tiruppur*

1. INTRODUCTION

Groundwater is a source of fresh water and fulfills domestic needs, supply to industries and agriculture also. Artificial Recharging structures are the practical approaches for groundwater management. In the beginning of 18^{th} century, ponds, canals were used to store water but they were not spatially located. To combat this issue, techniques like GIS & RS (remote sensing) has been launched to present the analysis spatially.

1.1 Existing Status

Tiruppur district was formed in October 2008 by carving out from Coimbatore and Erode districts. In 2013, Tiruppur District was formed with 9 taluks (Tirupur North, Tirupur South, Avinashi, Uthukuli, Palladam, Dharapuram, Kangayam, Udumalpettai and Madathukulam). The District is well drained by Noyyal and Amaravathy River and their served tributaries. Noyyal River divides the city into two halves – North and South. The "Noyyal" is known to be sacred river in Tamil history. Amaravathy is the considered as the major source of irrigation which covers the southern part of the district. River Cauvery is the largest river in the Tamil Nadu and river Bhavani queues the second rank. Noyyal covers two major dam named Orathuppalayam and Aathupalayam Dam which was commissioned in the aim of irrigating about 20,000 acres of land in Tiruppur and Karur districts.

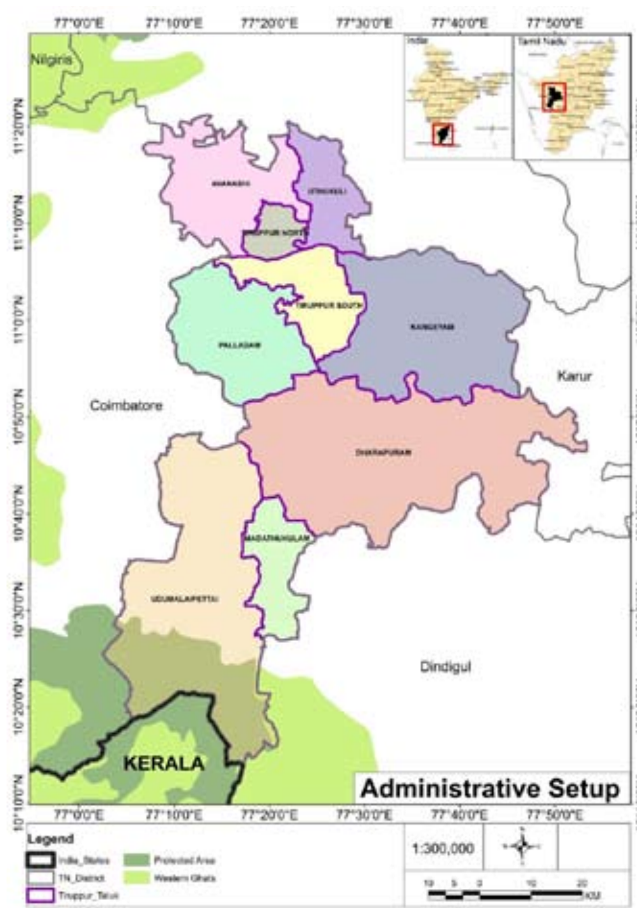

Fig. 1 : Administrative setup – Tiruppur district

Table 1 : Rivers of Tiruppur

Sl. No.	River Name	Origin	Length (km)	Stretch in Tiruppur (km)	Seasonal/ Perennial	Purpose
1	Noyyal	Vellingiri hills, Coimbatore	160	30	Seasonal	Irrigation
2	Amaravathy	Anaimalai hills, Udumalpet	282	121	Seasonal	Irrigation & Drinking
3	Palar	Anaimalai Hills		15	Seasonal	Irrigation
4	Nallar	Anamalai Reserve Forest		27	Seasonal	Irrigation

Tiruppur consists of 3 dams namely Thirumoorthy, Uppparu and Amaravathy.

Source: PWD Irrigation Department Tiruppur

Table 2 : Surface reservoirs of Tiruppur

Sl. No.	Reservoir Name	Situated on	Basin	Area sq. km	Capacity (TMC)	Ayacut area in Tiruppur (Acres)	Catchment Area (sq. km)
1	Bhavanisagar	Bhavani River	Cauvery	75.35	2.42	21866	4072.47
2	Amaravathy	Amaravathy River	Amaravathy	9.31	4	51973	839
3	Thirumoorthy	Palar River	Bharathapuza Palar sub basin	3.92	1.94	149606	80.29
4	Uppaar	Rain fed & Thirumorty dam	Bharathapuza	4.45	0.575	6060	903.56
5	Orathupalayam	Noyyal River	Cauvery – Noyyal river sub basin	2.2	0.616		
6	Aliyar	Aliyar River	Bharathapuza-Aliyar sub basin	6.48	3.86	-	196.84
7	Upper Aliyar	Aliyar reservoir	Aliyar sub basin		0.94		16.52

2. DETAILS OF THE STUDY AREA

The complete district comes under the river Cauvery basin. Noyyal, Amaravathi, Parambikulam-Aliyar and Palar are the significant sub basins. Noyyal sub basin covers the northern part of district and Amaravathy river basin covers the southern part of the district. Nallar is a tributary of Noyyal River which flows in south east direction. Amaravathy River gains the longest tributary of Cauvery River. Amaravathy flows in northerly direction and is fed by South-west monsoon. Palar River flows in North-West direction through Tiruppur and joins Thirumoorthy Dam in Udumalaipettai Taluk.

Noyyal and Amaravathy are analysed 5^{th} order streams whereas Palar and Nallar are recorded as 4^{th} order stream. Noyyal and Amaravathy are tributaries of Cauvery River which is the 7^{th} order stream and Palar is a tributary of Bharatapuzaha river which is 6th order stream. Also River Bhavani flowing northwards of the District is 6^{th} order stream. The total no of streams are 3450 and the total length is of 4452 km.

- **Geology, Lineament and Geomorphology**

Geology and geomorphology regulates the rate and movement of ground water. The entire Tiruppur District is comprised of with Archaean Rock formation which are weathered and fractured. (Kavitha T, 2013) Hornblend-Biotite Gneiss is the dominant rock type in the District. The ground water existence along certain lineaments which are deeply weathered and fractured zones, (Thirunavukkarasu P, 2013) locally have the potential of aquifers. The geomorphic landforms of district are

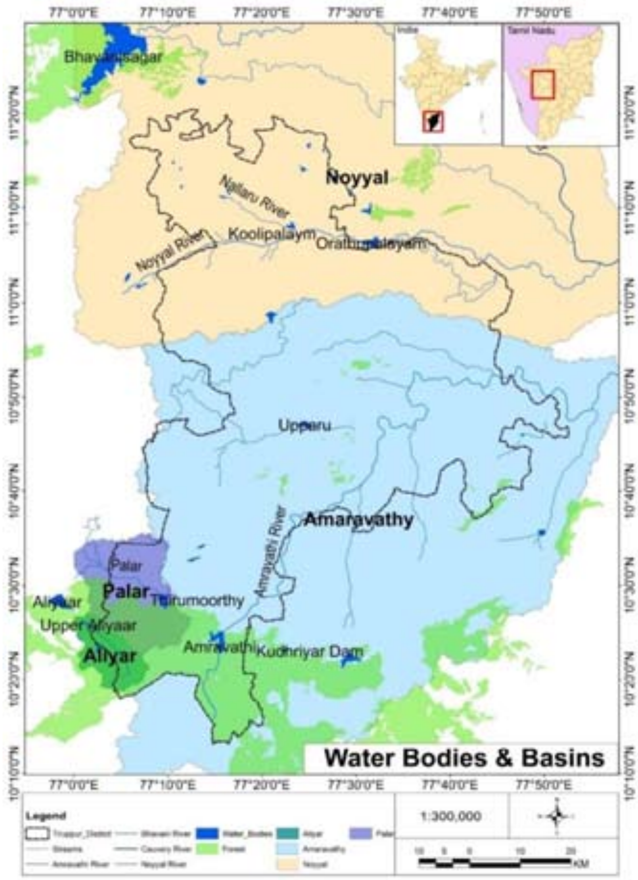

Fig. 1 : Water bodies and basins of Tiruppur district

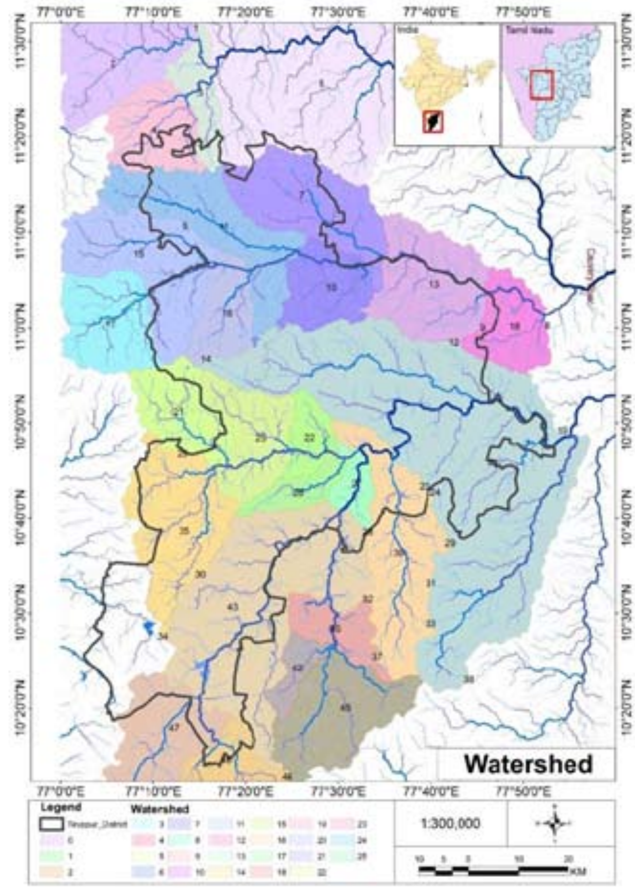

Fig. 2 : Watershed

broadly of two zones (i) Piedmont zones and (ii) Hills and Plateaus. Denundational origin – pediment is mostly studied in most of the district.

- **Drainage Density**

Drainage density is a manifestation of the closeness of spacing channels, thus providing a quantitative measure of length of stream with a square grid of the area in terms of km/km^2.

- **Slope**

The slope of an area is considered as an important parameter which regulates the groundwater recharge capability. The slope of district arrays from 0 to 50%.

- **Land Use**

The study area mostly consists of variable land uses such as crop land, plantation, current fallow followed by water bodies, built up rural and urban, grassland, scrub land, mining and forest.

- **Soils (A, 2017)**

The predominant soil types found in district are sand, loam, sandy loam, loamy sand, sandy clay loam, clay loam, sandy clay and clay.

3. MATERIALS AND METHODS

Seven Thematic layers have been generated, reclassify and consigned ranks and weightage by using Multi Influencing Factor (MIF) method. Weighted overlay process has been done in Arc GIS 10.1 using spatial analysis tool. In this study, seven thematic layers has

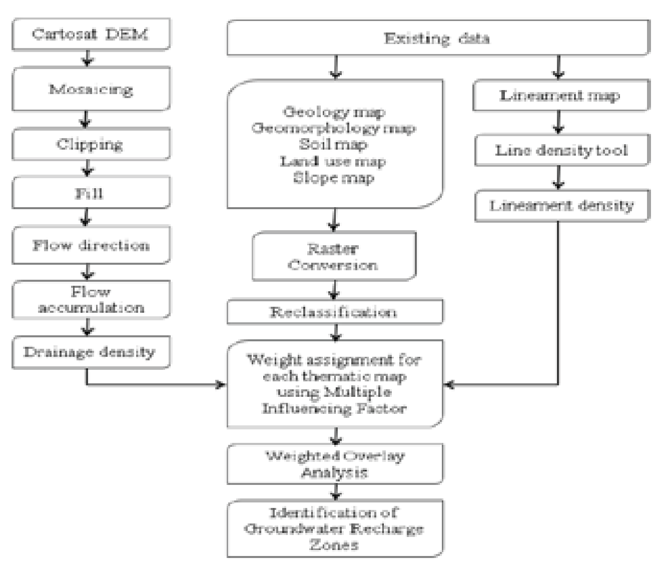

Fig. 2 : Methodology to obtain Groundwater Potential Zones

been prepared such as slope, land use, geomorphology, drainage density, lineament density, geology and soil map for obtaining Groundwater Potential Zones.

3.1 Preparation of Thematic layers

- **Preparation of Slope Map**

DEM file has been downloaded from USGS and analyzed as function of slope by using slope tool in surface analysis tool. Secondly, feature class file of slope gets converted to raster format and reclassified into three classes; good, moderate and poor. (Patil SG, 2014)

- **Preparation of Soil Map**

By using polygon to raster tool, soil map is converted into raster form. The soil type's classes are reclassified into three classes with assigned ranks to them.

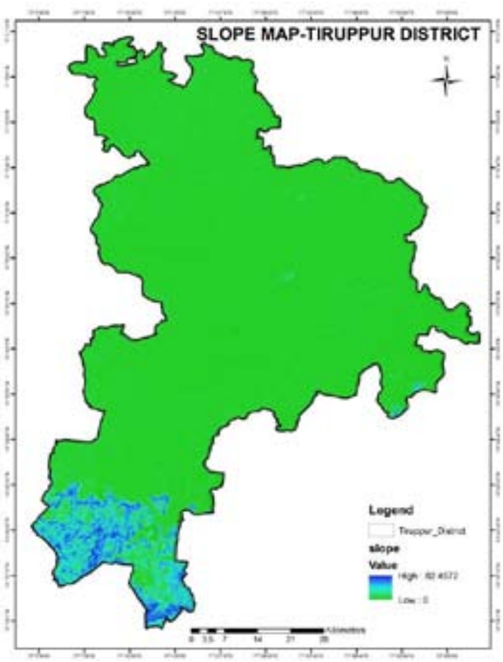

Fig. 3 : Slope map

(Source: TNAU , 2016)

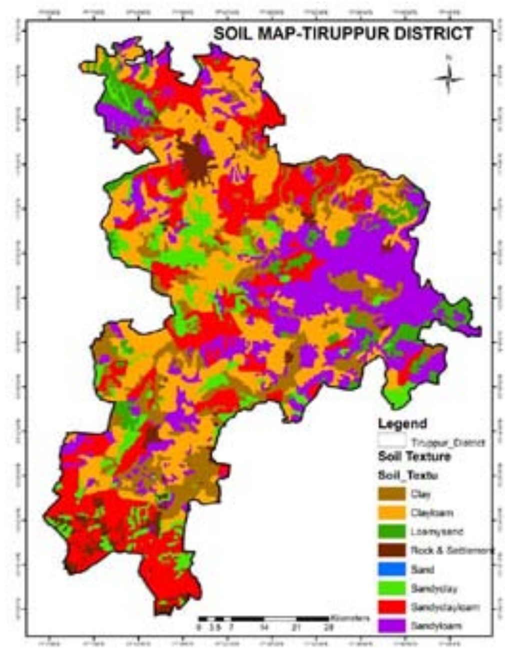

Fig. 3 : Soil texture map

- **Preparation of Geomorphology Map**

It portrays the association of geomorphological features with potential zones of groundwater as concludes from landforms and subsurface geology.

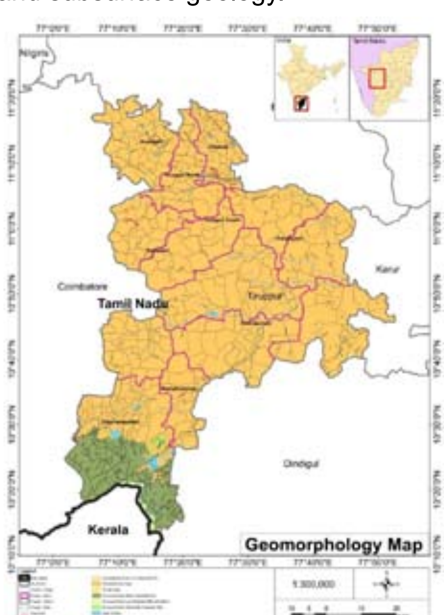

Fig. 5 : Geomorphology map

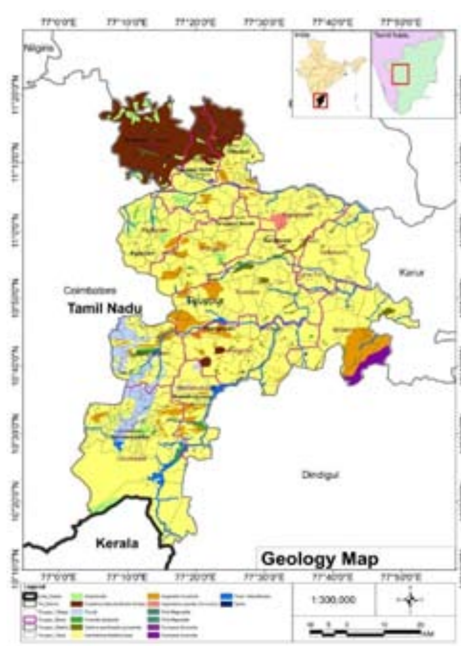

Fig. 6 : Geology map (Indian Geo-Platform of ISRO)

- **Preparation of Geology Map**

Geological characteristics plays an important role in identifying Groundwater Potential Zones. (PS, 2013)

- **Preparation of Land Use Map**

Land use map is collected from Bhuvan site , converted to Raster Format and reclassified into three classes and assign weightages and ranks based on the contribution to central focus.

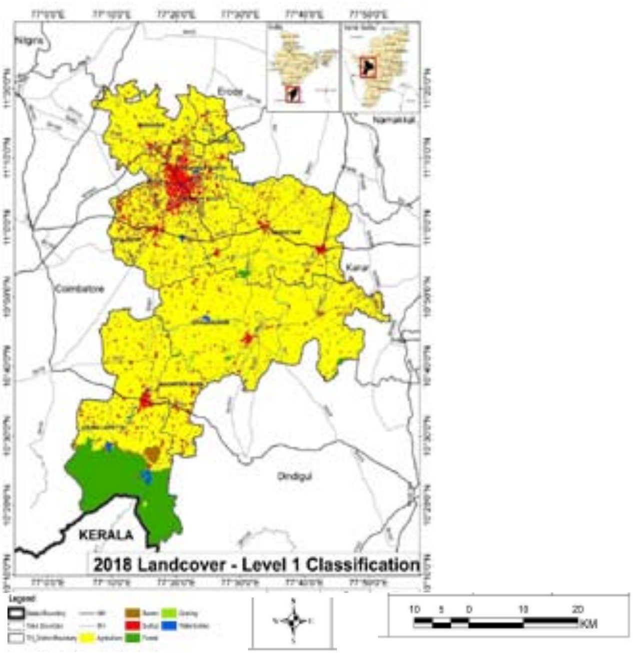

Fig. 7 : LULC map

(Source : Bhuvan)

- **Preparation of Lineament Density Map**

Lineaments are fractured structures that picture the weaker zones of bed rocks. In rocky terrain, they represent zones of fracturing which increases porosity. (Kumar B, 2011)

Lineament map was taken from Bhuvan site and was prepared using area density tool in spatial analysis tool in GIS and at last classified onto three classes viz ; majorly present, minorly present and moderately present.

- **Preparation of Drainage Density Map**

DEM (30 m) was extracted from USGS and clipped. The file was filled using fill tool in hydrology tool bar to remove imperfections. After this, flow direction tool has been used to create a raster of flow direction from each cell to its steepest neighbor. Accumulation tool was used to with flow direction as input.

By using raster tool calculator, a unified Drainage density map was obtained. After getting Drainage density, focal statistics tool used to concentrate the streams and then by reclassify the drainage density into three classes according to their influencing property of groundwater recharge potentials.

3.2 Integration of Thematic Layers

Criteria Weightage Assignment

Seven thematic layers has been weighted overlay using Multi-Influencing Factor methods of that feature and their properties influencing groundwater potential zones. Each major and minor factor is given a weightage of 1.0 and 0.5 respectively. (Shaban A)

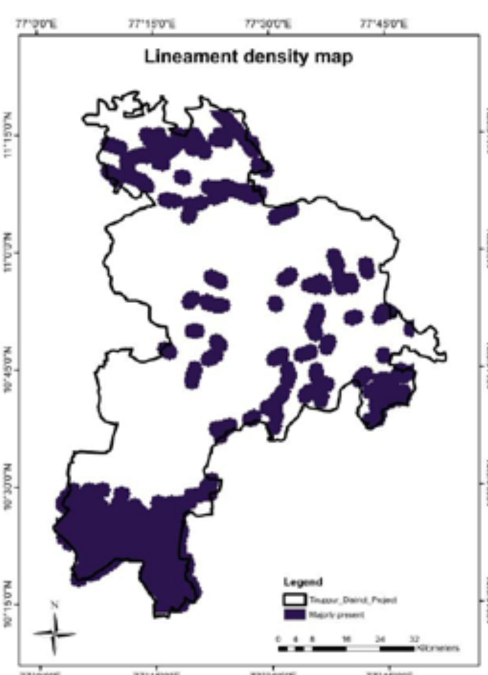

Fig. 8 : Lineament Density Map

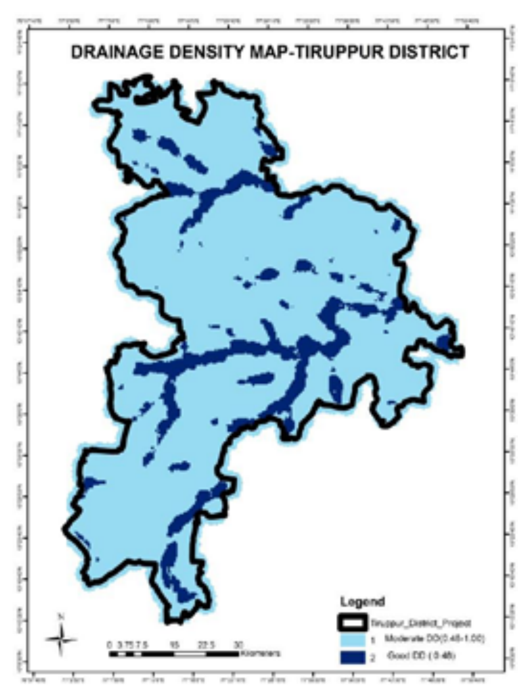

Fig. 9 : Drainage Density Map

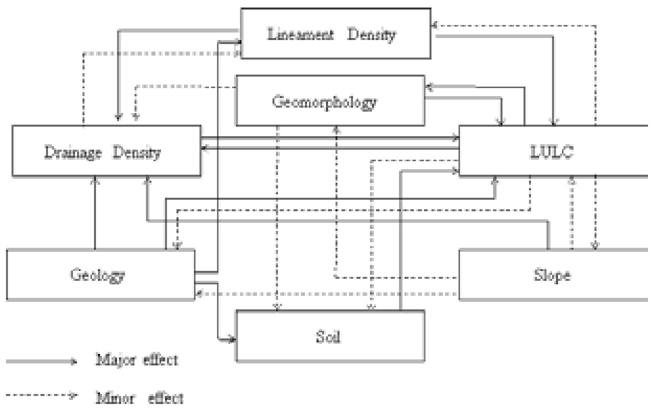

Fig. 3 : Interactive influences of factors concerning the recharge property

S. No	Factor	Major effect (A)	Minor effect (B)	Proposed relative rates (A+B)	Proposed score for each influencing factors
1	LULC	1+1	0.5+0.5+0.5+0.5	4	24
2	Geology	1+1+1+1	0	4	23
3	Lineament density	1+1	0	2	12
4	Geomorphology	1	0.5+0.5	2	11
5	Slope	1	0.5+0.5+0.5	2.5	15
6	Drainage density	1	0.5	1.5	9
7	Soil	1	0	1	6
			Total	∑17	∑100

Fig. 4 : Effect of factor influencing, relative rates and score for each factor (Saraf AK, 1998)

Multiple Influencing Factors techniques has been used for assigning weightage to all the thematic layers prepared and ranked accordingly to their contribution of creating Groundwater Potential Zones in Arc GIS 10 to obtain a unified map of Potential zones.

Sl. No.	Factors	Classes	Ranking (words)	Ranking (number)	Weightage (%)
1	Land use Land cover classes	Agriculture	Good	1	24
		Forest	Moderate	2	
		Built-up	Poor	3	
2	Geological classes	Hornblende-biotite gneiss,fluvial	Good	1	23
		Quartzite	Moderate	2	
		Granulite, Amphibolite	Poor	3	
3	Lineament Classes	Majorly present	Good	1	12
		Moderately present	Moderate	2	
		Minorly present	Poor	3	
4	Geomorphologic Classes	Denundational origin	Good	1	11
		Highly dissected hills	Moderate	2	
		Low dissected hills	Poor	3	
5	Slope classes (%)	0-5%	Good	1	15
		5-10%	Moderate	2	
		10-50%	Poor	3	
6	Drainage density Classes	0-0.48	Good	1	9
		0.48-0.68	Moderate	2	
		0.68-1.39	Poor	3	
7	Soil classes	Sand, loamy sand, sand loamy, loamy	Good	1	6
		sandy clay loam	Moderate	2	
		clay loam, sandy clay, clay	Poor	3	

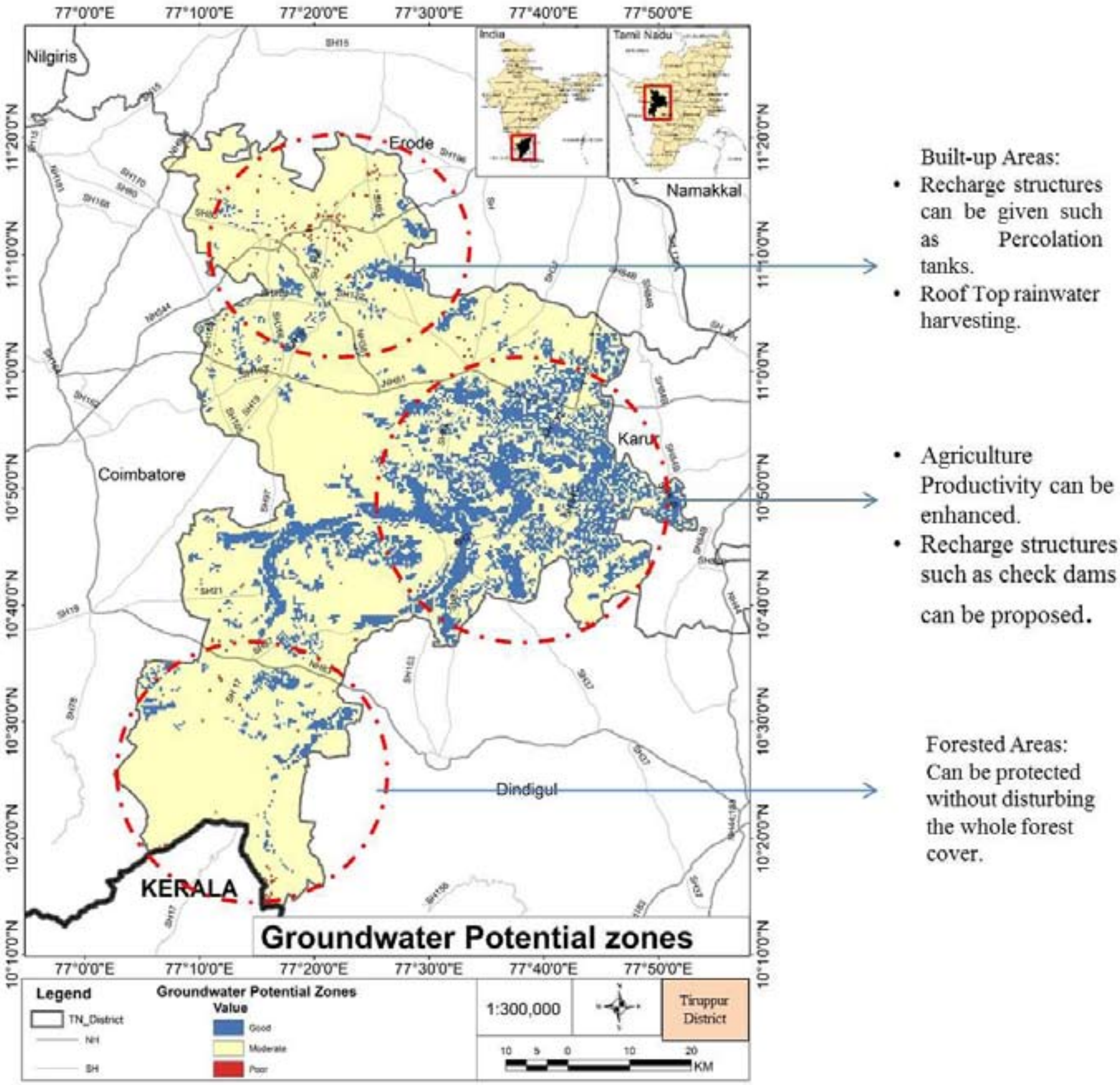

Fig. 12 : Groundwater recharge zoning map

Moderately Groundwater potential area covered is 4026 sq km (77%), followed by 1022 sq km (20%) which is covering the Good potential area.

(Source : Calculate by GIS)

3.3 Artificial Recharge Structures

It is known for the one of the effective techniques of groundwater resource management. Zones which show higher recharge potential are suitable for the construction of structures like Check dams, boulders bunds and percolation tanks.

Proposed Groundwater Recharge Structures

Site suitability analysis has been done through weighted overlay technique in Arc GIS. Based on the Groundwater potential zones map, variable sites according to suitability standards has been proposed .

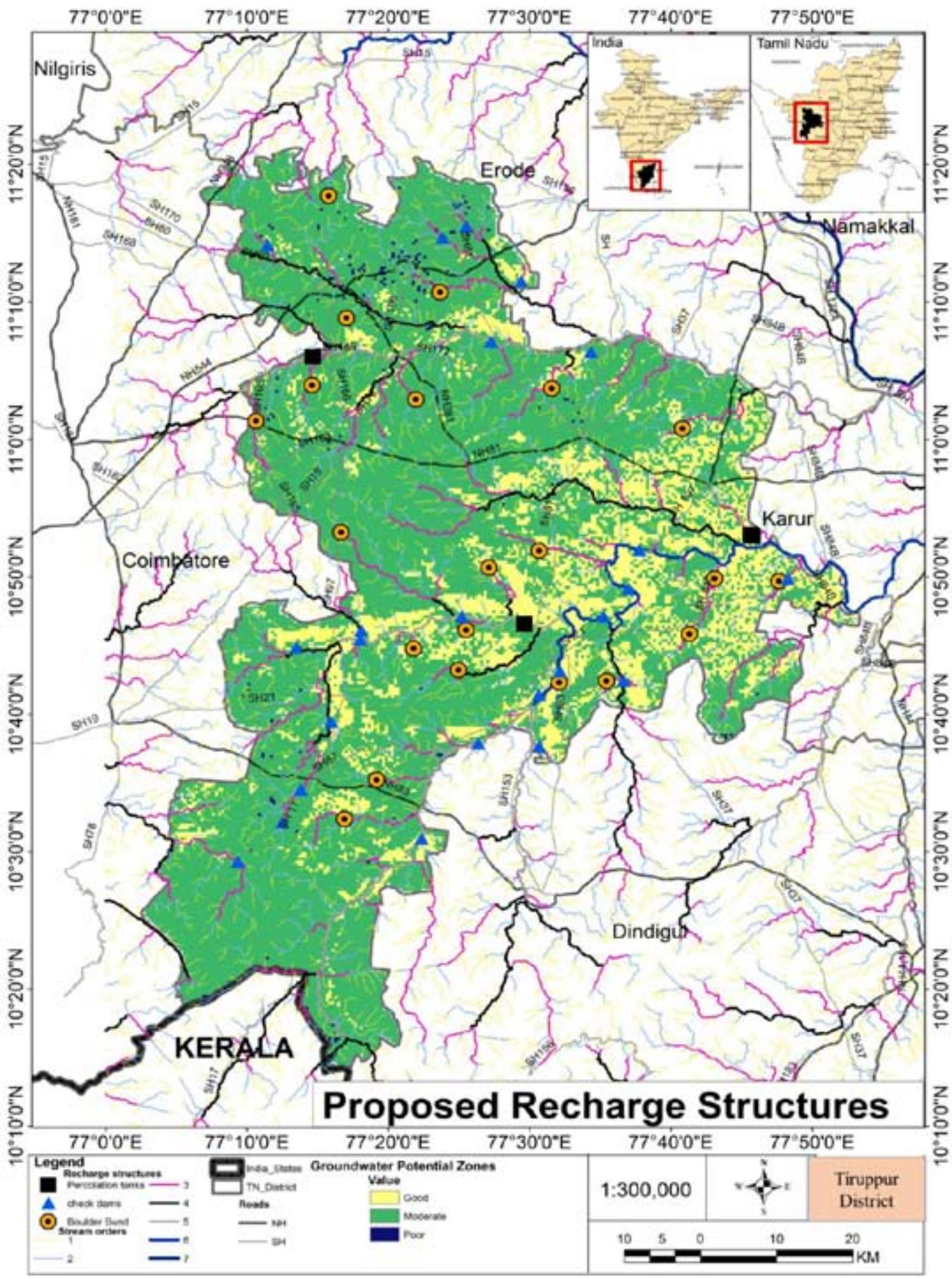

Fig. 13 : Proposed artificial recharge structures

Sl. No.	Recharge Structures	Stream order	Slope	Suitability
1	Boulder Bund	3 – 4 order Streams	< 12%	Suitable at catchments where stream courses have been deepened by erosion.
2	Check Dams	(>3rd order) streams	< 15%	Located near the vicinity of water bodies
3	Percolation Tank	Near 3rd to 4th order stream	< 10 %	Suitable on wasteland having fractures to have good groundwater recharge.

The main suggested recommendations for site suitability are:

1. Boulder Bunds: Bunds are located across 1st and 3rd order streams.
2. Check Dams: They are constructed across streams with higher order (> 3rd order).
3. Percolation Tanks: They are found across 3rd & 4th order streams to store surface runoff for groundwater recharge.

(*Source*: CGWB, Guide on Artificial recharge to Ground water, 2000)

4. CONCLUSIONS

The region with high lineament density, Agriculture, forest, low drainage density and low Slope and suitable geomorphology were categorized as high potential areas for groundwater zones. Kangeyam and Dharapuram taluks shows the good potential for Groundwater recharge followed by Udumalaipettai and Madhatukulum. Avinashi and Uthukuli taluks ranges from moderately to poor groundwater potential zones. Moderately Groundwater potential area covered is 4026 sq. km (77%), followed by 1022 sq. km (20%) which is covering the Good potential area. The overall results identifies suitable recharge structures at different potential zones and also according to the standards prescribed by CGWB.

REFERENCES

1. (2000). CGWB, Guide on Artificial recharge to Ground water.
2. A.R. (2017). Identification of Potential Groundwater Recharge Zones Using Remote Sensing and Geographical Information System in Amaravathy Basin. Journal of Remote Sensing & GIS, 10.
3. Indian Geo-Platform of ISRO. (n.d.). Retrieved from Bhuvan: bhuvan.nrsc.gov.in
4. Kavitha T, G. A. (2013). Geomporphometric Analysis of Amaravathy Basin,Tamil Nadu. Water Resources Development and Management, Mittal publications.
5. Kumar B, K.U. (2011). Ground water recharge zonation mapping and modeling using Geomatics techniques. Int J Environ Sci 1: 1670.
6. Patil SG, M. N. (2014). Identification of groundwater recharge potential zones for a watershed using remote sensing and GIS. Int J Geomat Geosci .
7. PS, P. (2013). Groundwater Potential Zoning at Kancheepuram using GIS.
8. Saraf A.K., C. (1998). Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. . Int J Remote Sens.
9. Shaban A, K.M. (n.d.). Use of remote sensing and GIS to determine recharge potentials :lebanon.
10. Thirunavukkarasu P, A.N. (2013). Integration of remote sensing and geographic information system for delineate groundwater potential zone in the Amaravathy sub-basin, Tamil Nadu. NGWC 2013 on Problems, Challenges and Management of GW in Agriculture.

National Workshop on

Developing Comprehensive and Scientific Mechanism/ Model for Forecasting of Hydrology for Hydro Electric Projects

25 April 2019, New Delhi

BRIEF REPORT

Inaugural Address by Shri Sanjiv Nandan Sahai, Additional Secretary, Ministry of Power, Government of India

SJVN Ltd., in coordination with Central Board of Irrigation and Power (CBIP), organized a National Workshop on "Developing Comprehensive and Scientific Mechanism/Model on Forecasting of Hydrology for Hydro Electric Projects", on 25 April 2019 at India Habitat Centre, New Delhi.

This workshop was an effort to bring together team of experts to have a discussion on this preponderant issue and to be able to adopt sound and successful action for short term forecast, which would contribute towards a rational use of the Renewable Water Resources.

The specific objectives of the workshop were the following:

- Familiarizing the participants with the requirement for development of latest Model/ Systems for hydrology forecasts in hydro projects, vis-à-vis the present practice
- Developing a collaborative strategy and infrastructure for Extended Model Forecasting through new approaches including participatory/Joint methods.

The workshop was attended by more than 90 representatives from various departments such as Bhakra Beas Management Board (BBMB), Brahmaputra Board, Central Water Commission (CWC), Central Electricity Authority (CEA), Damodar Valley Corporation (DVC), Ganga Flood Control Commission (GFCC), India Meteorological

Department (IMD), Indian Institute of Remote Sensing, Indian Institute of Technology Roorkee (IIT Roorkee), Narmada Control Authority (NCA), National Geophysical Research Institute (NGRI), National Institute of Hydrology (NIH), NHPC Limited, Snow & Avalanche Study Establishment, DRDO, THDC India Ltd., etc.

The workshop constituted a good opportunity to foster the networking among Hydro Project owners and concerned hydrology and meteorology practitioners.

In the Inaugural Address, Shri Sanjiv Nandan Sahai, Additional Secretary, Ministry of Power, Government of India, emphasized on the need for accurate data on hydrology for optimizing the use of water resources and overcoming uncertainties in stream flow predictions.

Shri Nand Lal Sharma, Chairman-cum-Managing Director, SJVN Ltd., in his key note address, emphasized the need to develop a model for extended stream flow forecast and justifying its importance especially in case of hydro projects, where government is putting lot of stress on renewable energy generation.

Shri R.K. Sinha, Member (RM), Central Water Commission and Dr. S.K. Jain, Director, National Institute of Hydrology, in their addresses appreciated the initiative of SJVN Ltd. and highlighted the activities of their respective organisations in the area of forecasting of hydrology.

Shri Nand Lal Sharma, Chairman-cum-Managing Director, SJVN Ltd., delivering key note address

Shri R.K. Sinha, Member (RM), Central Water Commission, addressing the participants during Inaugural Session

After the Introductory Presentation on "Hydrology and Its Uncertainties – A Challenge for Hydro Power Developers" by Shri S.P. Pathak, Chief General Manager, SJVN Ltd., Dr. S.K Jain, Director, NIH, made a presentation on "Hydrologic Modeling of Snow and Rain-fed Himalayan Catchments by Using a Semi-distributed Model" wherein he highlighted the various model approaches for snowmelt runoff modeling and uncertainties in Hydrologic Modelling, various inputs considered for modeling for Beas and Ganga Basins study area, and concluded that due emphasis should be on field surveys, collaboration between institutions and individuals, and increase use of models for WRPM including real time forecasting/operation.

This was followed by a presentation on Snow-melt Runoff Modelling Critical to Hydro Power Projects by Shri Goverdhan Prasad, Director, Hydrology (N), CWC, stated the importance of modeling. Dr. Shivam from National Remote Sensing Centre, Indian Space Research Organisation, then presented his short term model for glacier melt in Himalayan region using Energy balance approach and satellite data inputs.

The afternoon session, Shri Anil Vyas from BBMB highlighted spatial variation of snow water equivalent, depth of snow catchment area in the Himalayan sub basins. He showcased model developed by BBMB for Satluj and Beas basins and that GPM and TRM data used by BBMB from its 70 telemetering stations. He also stated that though BBMB RTDSS data comes under classified category but can be downloaded on request.

Address by Dr. S.K. Jain, Director, National Institute of Hydrology

Dr N.K Goel, Professor, IIT Roorkee along with Shri Niraj Aggarwal, DGM (Design) of THDC India Ltd., highlighted the important outcomes of the project specific model, developed for extended flow predictions at their end. He also stated the importance of installation of large number of gauging sites in the catchment area of project for getting a reliable time series of daily observed & simulated streamflows.

Welcome Address by Shri R.K. Bansal, Director (Electrical), SJVN Ltd.

In the presentation on “Operational Forecasting System to Process Real Time Hydro-Meteorological Data” by Shri Vasanth Kumar V, Deputy Director, FCA-1 Directorate, CWC, he highlighted on sharing of rainfall data from every stakeholders to generate a unified Rainfall data source. Dr. Ashok Kumar Das, Scientist-E, Hydromet Division, IMD, presented “Wx Early Warning System and Hydromet Support for Flood Forecasting”. Dr. B.P. Das, Former Engineer-in-Chief, Water Resources Department, Government of Odisha, shared his experiences on Impact of Climate Change on the Hydrological Response of River Basins Intercepted by Large Dams.

All the above solutions /proposals dealt with forecasting in short and medium term scenarios i.e. upto a maximum period of 7-10 days. However, the workshop met the objectives in promoting awareness for development of a model for extended period forecast and familiarizing the participants with the development of new approaches in this field of hydrology.

Delegates were encouraged to remain in contact and exchange information, in order to maintain the high momentum and commitments reached during the workshop, it was also decided to have joint collaboration with esteemed Institutes like NIH and IIT Roorkee to proceed with an action plan for implementation of a methodology for hydrology forecast in SJVN.

Panel Discussions and a Way Forward Deliberated by:

1. Dr. S.K. Jain, Director, NIH, Roorkee
2. Dr. N.K. Goel, Professor, IIT Roorkee
3. Shri S.P. Pathak, CGM, E.D, SJVN Ltd.
4. Shri Romesh Kapoor, CGM, C&SO, SJVN Ltd.

Following was the zist of panel discussions:

- All models discussed so far dealt with Short term and Medium term Hydrology Forecast. However the problem ahead was to develop a model to predict discharge for next few months to next year, especially for Hydro Projects under O&M stage, for setting up of MOU Generation Targets.
- There was acceptance of the need to understand development of sound models for basin wise catchment areas for short and medium term forecasts. Availability of hydrology data with CWC and project developer, could be used for analysis of such statistical/ dynamic models.
- An accurate forecast model should be developed jointly in association with IMD/BBMB/IIT/ THDC/CBIP/CWC/NIH, having proper ownership at SJVN end. The involvement of the institutions and the research organizations, working in the field of hydrology should be promoted and strengthened. This would increase clarity on the role of Hydrology in development of hydro projects.

Vote of Thanks by Shri V.K. Kanjlia, Secretary, CBIP

Introductory Presentation by Shri S.P. Pathak, Chief General Manager, SJVN Ltd., in the forenoon session being co-chaired by Shri Nand Lal Sharma, Chairman-cum-Managing Director, SJVN Ltd. and Dr. B.P. Das, Former Engineer-in-Chief, Water Resources Department, Government of Odisha

- Strengthening of Hydro Meteorological data and development of own observation network for real time data for Satluj Basin, as done by THDC/ BBMB, was stressed during panel discussions..
- Field Visits should be undertaken rigorously and strengthening of Automatic Weather stations in project specific catchment areas, under guidance from NIH/ IIT etc. This would serve as a useful tool for reaping the benefits to the maximum
- Investment should be made on training and contribution by in house manpower

RECOMMENDATION

After detailed deliberations during the workshop, general opinion of experts/ practitioners / participants was that this important subject which has direct impact on the performance of hydropower generators as well as power utilities and consumers, needs detailed analysis and research. As such, they all were of the view that this topic should be taken as R&D project under RSOP and CBIP should be requested to complete it in 2/3 years duration.

Afternoon Session being co-chaired by Shri R.K. Bansal, Director (Electrial), SJVN Ltd. and Dr. G.P. Patel, Director (WR), CBIP

Panel Discussions (L to R): Dr. N.K. Goel, Professor, IIT Roorkee; Dr. S.K. Jain, Director, NIH, Roorkee; Shri S.P Pathak, CGM, SJVN Ltd. and Shri Romesh Kapoor, CGM, C&SO, SJVN Ltd.

A view of the participants

IWRA News

30th UN WATER MEETING

31 January - 1 February, Rome

IWRA's Executive Director, Callum Clench, represented IWRA at the 30th UN-Water meeting held at the headquarters of the International Fund for Agricultural Development (IFAD) in Rome. He also joined the SDG 6 Integrated Monitoring Initiative Steering Committee meeting, which took place the day before at the FAO headquarters.

Participants discussed upcoming high-level events and reports that are being prepared on water and sanitation policy and practice issues, including on the implementation of Sustainable Development Goal (SDG) 6. The 30th UN-Water Meeting reviewed the consultation process that was undertaken during the final stages of the preparation of the Synthesis Report, including recommendations for the next Synthesis Report. During the meeting, the report from the SDG 6 Public Dialogue was launched.

Participants also addressed on-going work on SDG 6 indicators, upcoming global awareness-raising events, and the UN General Assembly (UNGA) resolution that calls for two high-level meetings – one in 2021 and one in 2023 – on water and sanitation issues, and options for how UN-Water could contribute to the preparations for these meetings.

At the conclusion of the meeting, UN-Water Chair, Gilbert Houngbo, highlighted the discussions on data for measuring SDG 6 progress, country-level activities for UN-Water, and the role UN-Water Partners can play in engaging with UN-Water and the specialised UN agencies, all of which captured UN-Water's collaborative approach to coordinating actions to address global water challenges.

1st WORLD SUMMIT ON LNOB

7 - 8 February, Geneva

IWRA collaborated with WaterLex to organise the 1st World Summit on 'Leaving No One Behind' that took place in Geneva from February 7th to February 8th, 2019. The event was also supported by the World Intellectual Property Organisation (WIPO), the World Meteorological Organisation (WMO), the Swiss Agency for Sustainability and Development, and Valser.

More than 100 experts, academics, water professionals and stakeholders from international organisations, government agencies, research institutions, non-profit institutions, and the private sector participated in this successful event. The format of the Summit was rather different from the usual conference, focusing around a competition to find the most innovative solutions for water and sanitation, that will solve problems for people in marginalised communities. The Summit Scientific Committee based its choices on criteria linked to the human rights to water and sanitation, including a human rights-based approach. The finalists had to demonstrate that the projects could be accessible to local communities, affordable and suitable for scaling up, through replication and policy reform.

The Innovation Award was selected by the judges on day one from the six finalist Flagship Projects, which had been pilot tested, and which showed the best chance of success. The winner in this category was Shervin Hashemi, a postdoctoral researcher from Seoul National University, with a nature-based solution for sanitation waste re-use as fertiliser. The project will be tested in rural Vietnam, using bio seeds as a source of locally-based biological treatment.

On day two, three prizes were awarded from fourteen finalist Exploration Projects for human rights-based approaches, such as community-managed rainwater harvesting, community-driven solutions in partnership with local government, and sanitation solutions for disabled children. Congratulations go to Deepthi Wickramsinghe (Sri Lanka), Eva Manzano (Colombia), Ramisetty Murali and Mekala Snehalatha (India).

IWRA'S 2019-2021 BOARD MEMBERS WORKSHOP

On March 10th and March 11th, IWRA organised a two-day Executive Board face-to-face meeting in Paris, France. The main purpose was assess IWRA's mission and vision, to brainstorm on IWRA's short, medium and long-term strategies, create synergies between the new IWRA committees, and for the board to interact with IWRA's Secretariat and meet international water experts based in the Paris region. To this end, four sessions were held, with Board members travelling from Australia, France, Korea and the United States. Moreover, on Monday, March

11th both a regular Executive Board teleconference was organised to brief and update Board members not able to attend in person, together with a cocktail reception with invited water experts from Paris. Overall, this workshop proved to be a fruitful experience for all concerned, and it will help to guide IWRA's work and activities over the next three years, and to provide the future Executive Boards with a proposed long-term roadmap.

Workshop group photo taken on March 11th, 2019. From left to right: Callum Clench (Executive Director), Yoonjin Kim (Board Director), Renée Martin-Nagle (Treasurer), Raya Stephan (Director), Guy Fradin (Secretary General), Gabriel Eckstein (President), Tom Soo (Membership Committee Chair), Jun-Haeng Heo (Director), Henning Bjornlund (Scientific, Technical & Publications Committee Chair) and Alice Colson (Project Officer).

Discussion session between IWRA Board members in Paris (March 10th, 2019).

IWRA President, Gabriel Eckstein (centre) welcoming invitees to the reception

IWRA Executive Board and staff exchanging with international water and environment experts.

ASIA WATER COUNCIL GENERAL ASSEMBLY

13 - 16 March, Manila

Following the recent 3rd General Assembly of the Asia Water Council (AWC) held in Manila from the 14-16 of March, we are delighted that IWRA has been elected to the Board of Governors of the AWC. We will be represented by one of our Vice-Presidents, Yuanyuan Li, as Governor, who comes from China. The Alternate Governor will be Gary Jones from Australia, another of our Executive Board Directors and who chairs the International Scientific Committee (ISC) for the XVII

General discussions at the AWC 9th Board of Council Meeting, 14 March 2019, Manila, the Philippines.

World Water Congress set to take place in Daegu in May 2020. This appointment helps IWRA to continue to build on its strong presence and participation in Asia. We look forward to furthering partnerships in the region and also congratulate all the other organisations that have been elected to the AWC Board of Council.

Following the elections, Gary Jones attended the 9th AWC Board of Council meeting on behalf of the IWRA, and was joined there by our colleagues from Daegu Metropolitan City who made a presentation about the upcoming XVII World Water Congress, which will be focused on "Foundations for Global Water Security and Resilience: Knowledge, Technology and Policy". The General Assembly afforded the opportunity to announce the call for abstracts for oral and posters presentations, special sessions and side events, as well as sponsorship and exhibition packages.

Over 60 delegates from 12 countries, across the 133 member organisations of AWC were in attendance in Manila. These included political representatives from the Republic of Korea, Pakistan and Nepal who were also attending the inaugural meeting of the Asian National Assembly Water Consultative Board.

IWRA WEBINAR: “WORLD WATER DAY – LEAVING NO ONE BEHIND”

22 March

This year, IWRA’s World Water Day webinar brought together a wide range of panellists and participants that came from international organisations, academia, and civil society to provide a number of perspectives on the fundamental theme of Leaving No One Behind. Discussions focused around issues such as expanding access to safe water and sanitation through new, insightful environmental, economic and judiciary perspectives and initiatives. Moreover, they exchanged ideas on how to increase participation in the water governance process, particularly for groups such as indigenous people who are often overlooked. In addition, a special emphasis was placed on the context of human rights, as well as access and affordability, which can act as a big barrier to access for many groups.

Nearly a 130 registrants participated of this webinar, while distinguished panellistsincluded Amanda Loeffen, Director General, WaterLex; Shervin Hashemi, Post-doctorate, Department of Civil and Environmental Engineering, Seoul National University; Alejandro Jimenez, Program Director for Content Development in Water Governance, Stockholm International Water Institute; Lesha Witmer, Steering Committee Member Women for Water Partnership; and, Alexander Otte, Associate Programme Specialist, Division of Water Sciences, UNESCO. This event was moderated by Scott McKenzie, PhD Candidate, University of British Columbia.

WORLD WATER COUNCIL’S 68th BOARD OF GOVERNORS MEETING IN BEIRUT

9 & 10 April

IWRA had a strong and active presence during the World Water Council (WWC)’s 68th Board of Governors (BoG) Meeting that took place 9 and 10 April in Beirut within the frame of the 7th Water Week in Lebanon. With many water representatives from international organisations and institutions, this event was a good occasion for IWRA representatives to inform and promote our approaching XVII World Water Congress (11-15 May, Daegu), set to be a key milestone in the Road to the 9th World Water Forum in Senegal in 2021!

From left to right: Yuanyuan Li, Vice-President, Soontak Lee, Fellow Member, Patrick Lavarde, Past President, Yoonjin Kim, Board Director, Ahmet Mete Saatçi, former Board Director, and Rabi Mohtar, Awards Committee Chair.

IWRA’s Vice-President, Yuanyuan Li, to the left during the WWC BoG in Beirut with Yongdeok Cho from Asia Water Council to the right. In the back row, the Association’s Past-President, Patrick Lavarde sitting in the middle with other WWC colleagues.

IWRA Past-President, Patrick Lavarde, promoting the XVII World Water Congress and the 9th World Water Forum at the 7th Water Week in Lebanon.

UNESCO INTERNATIONAL WATER CONFERENCE AND UNESCO I-WSSM AGREEMENT

14 & 15 May

Various members of the IWRA Executive Office and Executive Board were able to attend theUNESCO International Water Conference held at the UNESCO headquarters in Paris in May. This included Past President Patrick Lavarde, Secretary General Guy Fradin, Executive Board Director Farda Imanov, as well as Executive Director Callum Clench and Policy Officer Alice Colson. The meeting also provided the occasion to finalise an agreement between the UNESCO International Centre for Water Security and Sustainable Management (UNESCO i-WSSM) and IWRA. Specifically, IWRA will work closely with UNESCO i-WSSM to produce their annual Global Water Security Issues (GWSI) Papers series, which aims to document emerging water security-related topics and analyses around the world. Both organisations will work with distinguished researchers to produce case studies from relevant organisations that contribute to the better understanding of the economic, social, political, technological and institutional influences on current global water security, in connection to the Sustainable Development Goals. The specific objectives of the GWSI Paper Series include:

- To share research and studies on similar topics in order to strengthen cooperation among researchers engaged in the water sector internationally
- To encourage and enhance research on water security-related issues
- To identify solutions for improving global water security-related issues and to contribute towards achieving water security in the long term

IWRA Executive Director Callum Clench and IWRA Board Director Farda Imanov at UNESCO.

WORLD WATER COUNCIL'S 69th BOARD OF GOVERNORS MEETING IN SENEGAL

18 & 19 June

IWRA was represented at this Board of Governors (BoG) meeting by Executive Director Callum Clench, with Past President Patrick Lavarde and Secretary General Guy Fradin also in attendance in their official roles as co-President of the Forum organising committee and special advisor to the forum preparatory committee, respectively. One of the main purposes of the BoG was to review and contribute towards development of the new World Water Council strategic pathways. This was also the first opportunity for many of the Board members to visit Senegal where the 9th World Water Forum will be held in 2021. Also present from the IWRA Board of Directors was Farda Imanov (as a Governor of the World Water Council representing Azersu) and Yoonjin Kim (represent the Korea Water Forum).

IWRA Patrick Lavarde (Past President), Guy Fradin (Secretary General), YoonJin Kim (Board Director) and Callum Clench (Executive Director) present on this group picture in their various capacities.

9th WORLD WATER FORUM KICK-OFF MEETING IN DIAMNIADIO, DAKAR, SENEGAL

20 & 21 June

A bit more than a year after the 8th World Water Forum, it was time for the next host country, Senegal, to initiate the preparatory process for the upcoming 9th Forum, which will take place in Dakar, in 2021, on the focus "Water Security for Peace and Development". The official Kick-Off Meeting took place on June 20th - 21st in Dakar/Diamniadio, and gathered around four hundred participants. This meeting aimed at orienting the preparatory process and discuss the four priorities of the thematic framework, which are: Water Security, Rural Development, International Cooperation, and Means and Tools.

Both the Board and the Executive Office of IWRA were strongly represented during the Kick-Off Meeting: Patrick Lavarde, IWRA's Past President is also the co-President of the World Water Forum, Guy Fradin our Secretary General was the Rapporteur for the theme of Rural Development. Callum Clench and Alice Colson, from the Executive Office, also participated in the meeting and were rapporteurs for the Water Security theme, for which IWRA was recognised as a Strategic Partner.

This event was also a great opportunity to sign an MoU with Senegal and the World Water Council, to strengthen collaboration between the three parties turning IWRA's XVII World Water Congress (11-15 May 2020, Daegu, Korea) as a key milestone on the road to the Dakar, leveraging the water security theme of our next Congress.

OECD'S WATER GOVERNANCE INITIATIVE MEETING

20 & 21 June

IWRA's Communications Officer, Ignacio Deregibus, represented the Association at OECD's 12th Water Governance Initiative meeting held at GLS Campus in Berlin, on June 20th and 21st. More than 84 people participated in this productive event, used to launch of OECD's report on "Applying the OECD Principles on Water Governance to Floods: A Checklist for Action". Updates on WGI latest contributions to Global Agendas (SDGs, COP, Habitat III) and progress made on WGI working groups on Capacity Development and Indicators were also provided. Furthermore, participants also discussed very interesting peer-review National Policy Water Dialogues with Argentina, Peru and Brazil; water security and governance challenges in Africa; and learned more about Germany's water governance; and discussed the role of women in water governance.

Don't let the Water Run in the Sink, our Life's on the Brink!.

International Water Resources Association (IWRA)

Introduction

International Water Resources Association (IWRA) is a non-profit, non-governmental, educational organisation established in 1971. It provides a global, knowledge based, forum for bridging disciplines and geographies by connecting professionals, students, individuals, corporations and institutions who are concerned with the sustainable use of the world's water resources.

The goal of IWRA is to improve and expand the understanding of water issues through education, research and information exchange among countries and across disciplines.

IWRA seeks to continually improve water resource decision-making by improving our collective understanding of the physical, ecological, chemical, institutional, social, and economic aspects of water.

Objectives

- Lead and influence water policy and governance
- Develop and publicize methodological tools for assessment, improvement and conjunctive use of water
- Advance water resources planning, management, development, technology, research and education at international, regional, and national levels
- Provide a multi-disciplinary forum to address and discuss water issues
- Generate, synthesize, and disseminate knowledge and information in the area of water and related resources and the environment
- Encourage, promote and participate in international, regional, national and local programs and activities related to water resources for common benefit of humankind and biosphere

IWRA Geographic Committees

IWRA actively promotes the exchange of knowledge and experiences across countries and regions. The critical importance of local-base knowledge and experiences is strongly emphasised in our information exchange activities. The belief that sustainability requires interdisciplinary action and international cooperation is a driving force behind the Association.

IWRA has developed national or geographical committees in China, **India**, Japan and Ocenia to further implement its mission and focus its activities. These committees allow for extensive regional networking among IWRA members.

IWRA World Water Congress

Since 1973, IWRA has held a World Water Congress every three years in various locations around the world.

The objective of the World Water Congress is to provide a meeting place to share experiences, promote discussion, and to present new knowledge, research results and new developments in the field of water sciences around the world. For almost four decades the World Water Congresses have been excellent events for the identification of major global themes concerning the water agenda; and for the bringing together of a large cross-section of stakeholders for the development and implementation of decisions in the field of water.

Following is the list of IWRA World Water Congresses held so far:

XVIth World Water Congress in Cancun, Mexico
Dates: 29 May - 03 June, 2017
Theme: "Bridging Science and Policy"

XVth World Water Congress in Edinburgh, Scotland, UK
Dates: 25-29 May, 2015
Theme: "Global Water, a resource for development : Opportunities, Challenges and Constraints"

XIV^th^ World Water Congress in Porto de Galinhas, Brazil
Dates: 25-29 September, 2011
Theme: “Adaptive Water Management: Looking to the future”

XIII^th^ World Water Congress in Montpellier, France
Dates: 1-4 September, 2008
Theme: “Global Changes and Water Resources”

XII^th^ World Water Congress in New Delhi, India
Dates: 22-25 November, 2005
Theme: “Water for Sustainable Development, Towards Innovative Solutions“

XI^th^ World Water Congress in Madrid, Spain
Dates: 5 – 9 October, 2003
Theme: “Water Resources Management in the 21st Century”

X^th^ World Water Congress in Melbourne, Australia
Dates: 12 – 16 Mars, 2000
Theme: “Sharing and Caring for Water”

IX^th^ World Water Congress in Montreal, Canada
Dates: 1 – 6 September, 1997
Theme: “Water Resources Outlook for the 21 st Century: Conflicts and Opportunities”

VIII^th^ World Water Congress in El Cairo, Egypt
Dates: 13 – 18 May, 1994
Theme: “Satisfying Future National and Global Water Demands”

VII^th^ World Water Congress in Rabat, Morocco
Date: 13 – 18 May, 1991
Theme: “Water for Sustainable Development in the 21st Century”

VI^th^ World Water Congress in Ottawa, Canada
Date: 29 May – 3 June, 1988
Theme: “Water for World Development”

V^th^ World Water Congress in Brussels, Belgium
Date: 9 – 15 June, 1985
Theme: “Water Resources for Rural Areas and their Communities”

IV^th^ World Water Congress in Buenos Aires, Argentina
Date: 5 – 9 September, 1982
Theme: “Water for Human Consumption: Man and his Environment”

III^rd^ World Water Congress in Mexico City, Mexico
Date: 23 April, 1979
Theme: “Water for Human Survival”

II^nd^ World Water Congress in New Delhi, India
Date: 12 – 16 December, 1975
Theme: “Water for Human Needs”

I^st^ World Water Congress in Chicago, U.S.A.
Date: 24 – 28 September, 1973
Theme: “Importance and Problems of Water in the Human Environment in Modern Times”

Publications

- **Water International** (WI) is the official peer reviewed journal of the IWRA. Published by a major international publisher, Taylor & Francis, on behalf of IWRA, it is a leading source of information on international water resources research and policy.

- **IWRA Update** is a quarterly newsletter that contains news briefs about IWRA members, regional committee activities, calls for papers, and global water news.

IWRA also publishes **books, conference proceedings** and partners with various organisations to produce **special publications** and **affiliated journals** on water resources issues.

Awards

Since its creation, IWRA recognises the contributions towards water management and the excellence of water researchers, professionals and organisations. IWRA presents 5 main awards:

- **Crystal Drop Award** for individuals or organisations in recognition of their laudable contribution to the improvement of the world's water situation.
- **Ven Te Chow Memorial Award and Lecture** - IWRA has established a Chow Memorial Lecture program to honor its first president, as well as provide for an outstanding lecture at its Congresses.
- **IWRA Distinguished Lecture Award** - Every year, one distinguished member is invited to give this lecture at an IWRA sponsored conference.
- **Water International Best Paper Award** (Annual) is awarded to author(s) based on originality, innovation, technical quality, and contribution to water resources management.
- **Award for Excellence in Water Resources Management** seeks to recognise regional, national and local institutions that have exhibited sustained excellence in water resources management.
- **Young IWRA Member Scholarship Award** recognises a member under the age of 33 for an outstanding contribution to the management of water resources.

Membership

IWRA Offers following categories of membership

- Corporate
- Institution
- Individual-Fellow
- Individual-Regular
- Individual-Retiree
- Individual-Young Professional (35 years and younger)
- Individual-Full Time Student

Benefits to Members

- IWRA Publications in electronic format
- Access articles, posters and abstracts from the series of World Water Congresses
- Special rates for IWRA Events
- Latest updates on upcoming water events
- Make announcements on the activities on IWRA Website and Newsletter at no charge
- Opportunity to engage in professional networking and information exchange activities through participation in National and Regional Committees, mail lists server and IWRA News updates
- Opportunity to participate in international programmes and processes as representatives of IWRA

INDIAN GEOGRAPHICAL COMMITTEE OF IWRA (IGC-IWRA)

Water is one of the most precious gifts of the nature to mankind. Benign and life supporting in normal times, menacing during floods, and desperately sought in times of drought, the waters of the rivers, aquifers, springs, lakes, etc., have been part of our daily life. However, with the growing requirements of water for diverse purposes, water is becoming a critical and scarce natural resource and cannot be regarded as available in abundance as might had been believed earlier. It is widely recognized that many countries are entering into era of severe water shortage. The increase in demand is not only due to population growth but also due to improved life style of the people.

The International Water Resources Association (IWRA), established in 1972, with its secretariat in France, has been recognized and respected as a leading advocate in advancing the understanding and management of water resources worldwide.

The Central Board of Irrigation and Power (CBIP) is representing IWRA, in India, as its Geographical Committee, since 1991. The Indian Geographical Committee of IWRA (IGC-IWRA) has been involved in dissemination of information in the field of water resources through publications and training courses/seminars/conferences, both at National and International levels. The Indian Geographical Committee provides information regarding latest developments in the subject to its members.

IGC-IWRA offers following categories of the membership:

• Individual Membership for one calendar year:	Rs. 500.00
• Individual Members for 10 calendar years:	Rs. 4,500.00
• Individual Members for 20 calendar years:	Rs. 9,000.00
• Institutional Membership for one calendar year:	Rs. 5,000.00
• Institutional Membership for 02 calendar years:	Rs. 9,000.00
• Retiree/Student Membership for one calendar year:	Rs. 400.00

The members of IGC-IWRA will get the following benefits:

- A copy of the IWRA (India) Journal published on half yearly basis.
- Special rates at all IGC-IWRA events
- Announcements on upcoming events featured in IWRA publications and on the IWRA Website
- Have the opportunity to engage in professional networking and information exchange activities

One of the benefits to the Institutional Members is enrollment of their 05 representatives as Individual Members of the IGC-IWRA, besides promotion of activities through IWRA (India) Journal.

For membership and other details, please contact:

Mr. V.K. Kanjlia
Member Secretary
Indian Geographical Committee of IWRA
C/o Central Board of Irrigation and Power
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Seminar on

INTEGRATED WATER RESOURCES MANAGEMENT

14-15 November 2019, New Delhi

The concept of IWRM emerged around the 1980s in response to increasing pressures on water resources from competition amongst various users for a limited resource, the recognition of ecosystem requirements, pollution and the risk of declining water availability due to climate change.

The three basic "pillars" of IWRM are the enabling environment of appropriate policies and laws, the institutional roles and framework, and the management instruments for these institutions to apply on a daily basis. IWRM addresses both the management of water as a resource, and the framework for provision of water services to all categories of users, and it addresses both water quantity and quality. The basin/sub basin must be recognized as the basic unit for planning and management, and a firm societal commitment and proper public participation must be pursued. India has not yet reached the level of Water Resources Development as has already been achieved by many developed countries; therefore, there is a need for India to undertake developmental measures along with management measures.

Central Board of Irrigation and Power is going to organize the Seminar on the subject, with the objective to apprise the delegates with the process, which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystem.

Following will be the topics for discussion during the Seminar:

- Integrated Water Resources Management: An Overview
- Command Area Development
- Flood Management in India
- Water Use Efficiency in India : Governance and Management Challenges
- Health Aspects of Water Resources
- Role of Educational Institutions in Water Resources Development
- Environmental and Social Aspects
- Water Quality Aspects
- Water Audit
- Impact of Climate Change on Water Resources
- Drinking Water Supply

Case studies on the topics proposed and allied topics are invited. Intending authors may send the full text of their case studies, by 15 October 2019.

For further details, please visit :

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